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No. 125

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No. 125

EFFECTS OF NONIONIZING ELECTROMAGNETIC RADIATION

This serial publication contains articles, abstracts of articles and news items from USSR scientific and technical journals on the specific subjects reflected in the table of contents.

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CONTENTS | PAGE

CONTENTS (Continued) Page

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SURVEY OF EFFECTS OF CONTINUOUS AND ALTERNATING LOW-FREQUENCY MAGNETIC FIELDS

Moscow VOPROSY KURORTOLOGII FIZIOTERAPII I LECHEBNOY KUL'TURY in Russian No 6, 1978 pp 64-69

[Article by V. M. Bogolyubov and L. A. Skurikhina, Central Institute of Health Resort Medicine and Physical Therapy, Moscow, submitted 28 Jun 78 "The Biological Action of Continuous and Alternating Low Frequency Magnetic Fields"]

[Text] The magnetic field (MF) is a special kind of matter by means of which communication and interaction is realized between motive electric charges. It is exerted by the forces of attraction of motive opposite charges and unidirectional currents and the forces of repulsion of like motive charges and oppositely directed currents. These forces acting on a single motive charge are called Lorentz forces. The magnetic properties of different substances, including living tissue, are caused by the orbital movement and internal angular momentum (spin) of the electrons. These movements are regarded as microcurrents the magnitude of which characterizes magnetic momentum. Diamagnetic and paramagnetic substances are distinguished. In the atoms or molecules of certain metals (bismuth, silver) and phosphorus, sulfur, carbon, water and most organic substances (carbohydrates, protein) the magnetic momentum of electrons does not add up to the total magnetic momentum of the atom or molecule. Such substances are called diamagnetic. Substances in which similar compensation for the magnetic momentum of the electrons does not occur (alkalines and alkaline-earth, water solutions of metals and elements from the ferric series) are called paramagnetic. Living tissues are among the diamagnetic substances. Their magnetic transmittancy shows how many times greater magnetic induction of a field formed by a magnetizing current in tissue is than the induction of a field formed by the same current in a vacuum. The magnetic transmittancy of different tissues is close to one. According to this principle an external MF exerts practically no selective action on tissue.

The wide use in the past two to three decades of MF's of different intensities in industry, science, astronautics (to protect the crew of the vessel

from cosmic radiation) has aroused considerable interest in their biological action.

The action of the MF on the organism is connected with the initial physico-chemical processes developing during absorption--the interaction of their energy with the tissues. The nature of these processes has still not been sufficiently clarified. The possibility of three physical phenomena occurring during the process is accepted: 1) the orientation and concentration in the body fluids of macromolecules which are responsible for the dynamics of the physico-chemical processes and biological reactions; 2) elastic vibrations of the nerve and muscle fibers during the diffusion in them of bioelectric impulses capable of distorting or delaying the latter under the influence of heterogeneous MF's; 3) magnetodynamic inhibition of the circulation of blood and other body fluids (Ya. G. Dorfman). Newer data on the physico-chemical bases of the initial mechanisms of the biological action of MF's are presented in articles by V. M. Aristarkhov et al, Ye. Z. Gak et al, Yu. V. Berlin et al, and M. A. Shishlo et al ("Resktsii biologicheskikh sistem na magnitnyye polya" [The Reaction of Biological Systems to Magnetic Fields], Nauka, 1978). Despite the diamagnetic nature of biological molecules and the fact that they require insignificantly little energy even in strong (1000 Oe) MF's, the influence of MF's on them is undoubted. Many organic molecules are packed into domains at a given temperature. Under the influence of an MF strong orientation events arise in them: long chains of molecules align themselves in the direction of the MF; in this case the magnitude of the energy acquired by them is great. The orientation events are more pronounced in the lipid membranes, myosin and the mitrochondria, and they play a major role in the regulation of many biochemical processes and transmembrane transfer of ions (Se, Ye. Bresler). Anisotropy--i.e., heterogeneity of the magnetic receptivity of the macromolecules--is considered to be their source. When MF's interact with tissues the changes in the organism may be caused by change in the spin of the electrons of the atoms and molecules (Maklochlan), as may the friction of the protoplasm on the cellular membrane as the result of disturbance of the pathways carrying the charges of particles of protoplasm (P. V. Savostin, 1937).

The chemical changes occurring in tissues under the influence of MF's are associated with a change in the coupling of some molecules which require little energy (Gross) and with change in the properties of the moving free and bound water in the organism, particularly its surface tension, viscosity, electric conductivity and dielectric transmittancy (V. I. Minenko et al; R. Setlow and E. Pollard; D. M. Umanskiy, 1965; S. A. Bruns et al). The possible influence of MF's on the Brownian rotation of molecules causing fragmentation of their side chains and change in their specificity has been theoretically substantiated (Valentinuzzi). Considering the chemical changes in the organism under the influence of MF, the direct influence of the latter on the equilibrium and rate of chemical reactions and on the chemical processes has been assumed (M. A. Shishlo). Gleichman considers the magnetic resonance arising between the energy field and the elementary energy of the atoms and molecules of the organism to be the basis of the

action of MF's. The magnetobiological effects are also viewed as the result of information introduced into the organism and causing redistribution of energy in it (M. F. Barnothy, 1959, 1963; I. M. Barnothy, 1960, 1962; M. F. Barnothy and I. M. Barnothy; A. S. Presman). Research has indicated that the enumerated changes arise under the influence of strong (1000-10,000 Oe) MF's. Based on the complexity of the parameters of MF's and the diversity of the mechanism of their interaction with different formations of the organism, apparently a number of possible physical chemical mechanisms of the biological action of MF's must be assumed. Here Y. A. Kholodov (1977) includes the induction of electromotive forces (EMF), change in the orientation of the macromolecules, influence on organic fluids, crystals, change in the polarization of nuclei and electrons and influence on the transmittancy of the cellular membranes.

Modern magnetotherapy is based on experimental studies concerning the influence of MF's on the functional condition of the nervous and endocrine systems, the metabolism of substances, the function of different systems and organs, different properties of blood, and tissue morphology. Short-term exposures (2 min) to continuous magnetic fields (CMF) close to the threshold intensities (50 Oe) result in the predominance of low-frequency potentials on electroencephalograms (EEG) of rabbits persisting for 10-15 min after termination of the exposure (Yu. A. Kholodov et al). In repeated exposures (for 1-3 min) on the head of an animal as well as during prolonged (3 hr) daily exposures, an obvious summation effect was noted, since the daily pause in the action of the MF does not result in restoration of the initial EEG (Yu. A. Kholodov, 1966). According to the data of the change in the biopotentials under the influence of CMF, the activity of the hypothalamus is in first place; of the cerebral cortex, in second place and of the reticular formation of the midbrain, in last place (Yu. A. Kholodov, 1966). When the action of continuous (3, 4 Oe) and pulsed (0.5 Hz) MF's (for two min) on the reticular formation of the midbrain of animals was compared it was determined that pulsed and sinusoid MF's result in more pronounced and stable changes than continuous MF's. The restoration of the spectrum of biopotentials was observed during the first minutes after termination of the action of the MF (Ye. Ya. Voytinskiy et al). Under the influence on the animal's head of a CMF (40 Oe with a gradient of 20 Oe/cm, four times daily for 30 min) desynchronization of the electrical activity of the brain arising because of application of the EMS is observed. In the substantia medullaris an alternating current of as much as 2 V arises. After 7-10 days of this kind of influence slow, low-valent oscillations predominate; they are reduced 12-14 days after the exposure (V. I. Lapin and I. P. Pshenichniy, 1974).

The influence of CMF on the head of animals (220-300 Oe, for 60 min) is accompanied by a productive reaction in the brain without effecting the neurons, and the influence of CMF for 60-70 hours is accompanied by productive-dystrophic disturbances in the glia and destructive disturbances in the nerve cells (M. M. Aleksandrovskaya and Yu. A. Kholodov). Intensive exposures to CMF at an intensity of 2000 Oe for 30 min over the course of 5

days still does not disturb a firmly established conditioned reflex in mice, while under exposure to 3000 Oe for 3 min, its stability decreases after 1-3 days and under the influence of 5000 Oe for 1 hour memory is significantly disturbed in 73-78 percent of the animals. A CMF at an intensity of 3000 Oe for 30 minutes does not change the conditioned reflex activity of mice which several days earlier were in a CMF at an intensity of 2000 Oe; this indicates adaptation to the CMF (Ch. Asabaev and S. G. Chernomorchenko). In addition, Renyhe et al have shown that a CMF at an intensity of 8000 Oe and 10 Oe at a duration of 5 min inhibits the development of conditioned reflexes in rats, the latent period of the reaction increasing while its frequency decelerated. A previously acquired conditioned reflex decreased under the influence of a CMF at 8000 Oe and 10 Oe. Under the influence of an alternating magnetic field (AMF) (50 Hz, 1000 Oe for 3½ hours and 10 hours and over 2, 4, 6 and 15 days for 5 hours) the ultrastructure of the neurons and neuroglia of the cerebral cortex undergo more pronounced changes, involving not only protein synthesis but also the energy processes, than under the influence of a CMF (450 Oe, for 30 days 1 hour and 20, 200, 2000 Oe for 3½ hours and 10 hours). The indicated changes disappear in 2-4 hours, and the functional activity of the mitochondria increases (Yu. M. Ir'yanov; S. R. Razykov and M. S. Abdullakhodzhaeva).

A great number of studies have been devoted to investigation of the influence of MF's on the properties of blood. Their results are not uniform. In experimental works, M. F. Barnothy and I. M. Barnothy (1959-1970) showed that a CMF at an intensity of 4000 Oe at a gradient of 30 Oe/cm for 5 weeks gives rise to phase changes in the content of the regular elements of blood. The number of erythrocytes did not change during the exposure, but the number of leucocytes decreased by 30-40 percent. By the termination of the exposure to the CMF the number of leucocytes had increased by 100 percent of the initial level. During the next two weeks it again dropped below the initial level and returned to the norm only two months later.

A. M. Demetskiy and S. F. Surganova observed a decrease in the number of leucocytes, monocytes and lymphocytes with an increase in the number of erythrocytes and thrombocytes and a decrease in their aggregation and adhesions after exposure to the CMF (100 Oe for 10 min during 7 days). The number of leucocytes did not decrease after the rats had stayed in a CMF (300 Oe at a gradient of 20-24 Oe/cm for 6 hours a day) for five days, but three days after termination of the exposure it decreased to five (normally 51). After 10-day exposure to the indicated field the number of leucocytes decreased to 18, and after 15- and 20-day "magnetizing," the effect of decrease in leucocytes disappeared, a change which is attributed to the adaptation of the animals to the factor. The phagocytic activity of the leucocytes in this case changed in relation to the changes in the content of leucocytes (D. G. Pel'ts et al). N. A. Kliment'eva and G. P. Garganeyev observed an increase in the number of leucocytes in animals after a 30-day exposure to a CMF (1500 Oe in the center and 50 Oe at the periphery). Bellossi et al (1971) detected no changes in the number of leucocytes and erythrocytes after exposure to a homogeneous M at an inductivity of 5200-7900 G. In this case the morphology of the leucocytes also did not change,

and the deformation of the erythrocytes was more pronounced than in the controls. After white rats were exposed to a CMF (2000 Oe) for 20 min, an increase in the number of erythrocytes was detected, especially on the 4th and 20th days after the exposure (Ya. I. Korpatovskiy et al). The content of erythrocytes and hemoglobin, as well as the relation of the individual white blood cells of animals after 1- to 3-hour and 1, 2, 3, 4, 5 and 30-day exposure to a CMF (1000 Oe) did not change, but after 24-hour exposure to this field the content of reticulocytes increased during the first days after the exposure and then decreased, not attaining its original level by the 3rd day (A. G. Borodkiha, V. N. Nakhil'nitskaya). In a study of the resistance of erythrocytes to hemolysis and ATPase and acid phosphatase activity in the membrance of the erythrocytes before and after exposure to a CMF (1300-1500 Oe for 1 and 3 days), E. V. Vinichenko and I. V. Tyunkov demonstrated intense discharge into the blood stream of young, unusually resistant erythrocytes with high enzymatic activity. According to the data of Gardner et al (1967) an MF at an intensity of 3800-10,000 Oe facilitates the deterioration of erythrocytes, which is manifested in acceleration of hemolysis of them.

The phagocytic activity of leucocytes in 49 healthy individuals and 121 patients with pyogenic infections increased significantly under the influence of a similar MF (4300-5100 Oe, 3 hours (Bellossi et al, 1974). In as much as any processes which result in an increase in the energy of the cell promote an increase in phagocytosis, the author came to the conclusion that a homogeneous MF exerts an influence on DNA molecules--the genes of regulation. This is consistent with M. F. Barnothy's hypothesis (1964) about the influence of MF's on the genetic code. In a later work Bellossi and Michon (1975) found the opposite effect--a decrease in the phagocytic activity of leucocytes in 30 patients with viral diseases of the liver and an increase in it in patients with pyogenic infections following exposure to a MF (4000 Oe for 2-3 hours). The cause of the different phagocytic activity of the leucocytes at the same intensity and duration of the MF is the different spatial orientation of the large molecules which results in antithetical functioning of leucocytes taken from patients with pustulent infections and viral diseases. In other investigations Bellossi and Barbatin (1975) observed an in vitro increase in the cytotoxic activity of leucocytes against tumor cells taken from patients with cancer of the liver subjected to the action of an MF (4000 G, 2-3 hours). They used the increase in the cytotoxic activity of the leucocytes in order to treat patients with cancer of the liver.

Shifts in the coagulation system of blood vary in dependence on the duration and intensity of the action of the MF. When the heads of animals are exposed to a high-intensity CMF (2000 Oe for 4 hours over 1.4 and 30 days) acceleration of blood coagulation during the first hours and days of exposure, insufficiency of thromboplastin formation on the 7th and 30th days, an increase in fibrinase activity after 4-hour exposure which dropped sharply on the 7th day and was restored to the norm by the 30th day (Z. M. Abdullina et al, 1974). A less intense CMF (50 Oe for 2 hours over 7 days) decelerates

blood coagulation after a single 2-hour exposure; a more pronounced effect is noted after seven 2-hour exposures. Here the indices of a coagulogram indicate the insufficiency of the total coagulation capacity of the blood, although at the end of the period of investigation the requirement for prothrombin increases. The antithrombinic and fibrinolytic activity of blood did not change significantly (K. Zh. Sulenov). Under the influence of a CMF (200-300 Oe, 2500 Oe 10-15 min) and an AMF (10, 50, 200 Hz, 100 Oe, 15 and 30 min) suppression of the thromboplastic activity of blood was noted in experiments in vitro. The decrease in the hemocoagulation effect in blood is connected with the fact that the MF promotes the liberation from the regular blood elements and the tissues of compounds active in coagulation and their entry into the blood stream (V. F. Rysyaev and Yu. A. Arsent'ev).

In a study by R. P. Kikut et al (1976 a, b) the importance of the orientation of the lines of force of the MF for the nature of change in the function of the coagulation systems of the blood was demonstrated. Under the influence of a CMF of 2500 Oe oriented perpendicularly to the vessel, the authors detected agglutinates at the 5th-10th minute and a thrombus in the vessel on the side of the positive potential (of the induced EDS), while on the side of the negative potential an insignificant change in the height of the blood flow was observed. The authors propose to use this induced bioelectric phenomenon of local thrombus-formation in an aneurism without direct application of an electrode in order to treat aneurisms of the deep vessels. Hackel et al observed increased agglutination of erythrocytes under the influence of a low-intensity MF (50 Oe or higher). V. I. Maryutin and V. K. Dvorovenko demonstrated an increase in the specific resistance to 15-20 Ω/cm and deceleration of the coagulability of the blood of animals under the influence of a CMF (2000 Oe). They attribute these effects to the action of Lorentz forces on the ion stream and the erythrocytes moving in it. According to V. A. Vardanyan, the action of Lorentz forces on charges moving in the blood may significantly decelerate the rate of blood flow with prolonged application of an intense MF, which in turn increases the gradient of pressure in the vessels. He recommends a strong MF for internal hemostatis and regulation of the rate of blood flow.

Many investigators (P. I. Gorshenina and A. E. Frul'kes; A. I. Shchepetil'nikova; L. M. Merkulova and V. V. Amosova; Z. M. Abdullina, 1970 b) have studied the morphological changes in different tissues after exposure to MF's. The results of numerous investigations are more fully summarized in the works of I. V. Toroptsev, I. V. Toroptsev and G. P. Garganeva, I. V. Toroptsev et al. After a single exposure to an MF (200-7000 Oe, 6½ hours) changes of a pathological but not catastrophic nature arise in a number of organs and systems of intact animals. In the first days after the exposure these changes intensify and then gradually disappear. These changes are most pronounced and stable in the sex glands. Disturbances in blood- and lymph-circulation appearing as spasm of certain arteries, paretic dilation of the capillaries, veins and lymph vessels with signs of stasis and hemorrhages in the serious membranes, and as hemorrhaging in the lungs are detected macroscopically. In the nerve cells productive-dystrophic

disturbances of the neuroglia, swelling and vacuolization of the nuclei and cytoplasm in some ganglionic cells of the subcortical ganglion in the anterior and posterior cornua of the spinal cord are demonstrated microscopically. In the lungs emphysema, change in the argyrophilic substance and the concentration of polysaccharides in the tissue are found. Destructive changes, swelling of the reticuloendothelial cells and an increase in the level of glycogen in the hepatocytes are detected in the liver. In the kidneys widespread necrosis and desquamation of the epithelium, the formation of peculiar cylinders and anemic regions are observed. Concentration of eosinophiles in tissue is found in bone marrow and in the sex organs part of the tubules are filled with the detritus of disintegrating cells, and desquamation of the spermatogenic and follicular epithelia and disturbance of water metabolism in its cytoplasm, spermatozoids and egg cells are found. In the tissues of the eye hyperemia of the sclera, edema and decrease in the sensitivity of the cornea, disturbance of lymph circulation in the cilliated body, change in the epithelium of the lens and necrobiosis of the ganglionic cells of the retina are observed after exposure to a CMF at 200 Oe. All other things being equal, the morphological changes are significantly more pronounced with exposure to pulsed and alternating MF's than to CMF.

The ultrastructural investigations indicate the high sensitivity to MF's of the mitochondria and granular endoplasmic network. A. P. Speranskiy et al observed a decrease in the content of mitochondria and increases in the number of cysts after exposure to a CMF (100 Oe for 30 min over five days). These changes disappeared within 24 hours. After exposure to a pulsed MF of the same intensity the indicated changes were less pronounced, but when the intensity of the CMF was increased to 400 Oe they were more substantial. Z. M. Abdullina et al (1974 b) observed changes in the mitochondria in the tubules of the kidney under the influence of a CMF at 2100 Oe for 4 hours over 1 and 4 weeks).

The ultrastructural changes in nerve tissue, particularly of the mantle cells and neurons of the trigeminal ganglion after exposure to an AMF and CMF (20-400 Oe for 3, 5 and 10 hours over 2, 4 and 8 days) are manifested as dilation of the cistern and tubules, a decrease in the number of ribosomes bonded to the membranes of the endoplasmic network, increase in sizes, change in forms, decrease in the density of the matrix, a reduction in the cysts of the mitochondria and disturbance of the intactness of their membranes, constriction of the cisterns of the Golgi apparati, increase in the fabrillar, and decrease in the granular, substance of the nucleoli. After termination of the exposure to the MF at different times the structure of the cells is restored. What is more, the functional activity significantly increases, a result which is indicated by the increase in the density of the matrix and increase in the number of cysts (Yu. M. Ir'yanov). According to the data of Yu. A. Kholodov, the cellular membranes most sensitive to MF's are the membranes of the mitochondria and the nucleus.

Many researchers have studied enzyme activity, tissue respiration and certain aspects of metabolism under the influence of MF's. According to these data and the results of M. A. Shishlo's studies, the changes in the rate of disintegration of enzymes in vitro, the changes in the ratio between free and

phosphorylating oxidation, the increase in glycolysis and the stress reaction of the intact organisms are the most significant. According to M. A. Shishlo's concept the probable cause is changes in the slight interaction of the submolecular organization of the living structures induced by the MF and resulting in quantitative changes in the chemical specificity of the reactions and possibly also by the changes in the properties of tissue water.

According to the research of a number of authors summarized by N. V. Vasil'yev and N. V. Vasil'yev et al the immunobiological activity of the organism is significantly changed in its specific and nonspecific components in diseases of viral, bacterial and protozoic character. The influence of MF's on the infectious process, the factors of natural humoral immunity, antobody-formation and the immunomorphological processes have been demonstrated. MF's of different characteristics may exert both stimulating and inhibiting influences on immunological reactions depending on the stage in immunogenesis when they are applied. Most frequently a phase response reaction on the part of the reticulolymphoid system develops under the influence of an MF. As a result fluctuation in the phagocytic activity of leucocytes and change in the system of complements--properdine and serum lysozyme--is observed.

The data presented in the present survey is part of an enormous number of investigations involving the influence of MF's on the organism. But they refute the opinion of a number of researchers which existed until very recently that the living organism has no special formations for perceiving MF's and that therefore there is neither a sensory nor a metabolic reaction to MF's in living organisms (D. N. Nasonov, "O prirody vozbuzhdeniya" [On the Nature of Excitation], Moscow, 1948; Yu. Ackerman, "Biofizika" [Biophysics], Mir, 1964). At the present time the accumulated data concerning the influence of MF's on the organism is being used to create a method of treatment--magnetotherapy.

BIBLIOGRAPHY

1. Abdullina, Z. M.; Mirrakhimov, M. M.; Prizhivoyt, G. N. In: "Magnitnoye polye v meditsine" [The Magnetic Field in Medicine], Frunze, 1974, p 75.

2. Abdullina, Z. M.; Chizhova, S. S.; Yasnobulko, S. Z. Ibid, p 115

3. Ackerman, E. "Biofizika" [Biophysics], Moscow, 1964.

4. Aleksandrovskay, M. M.; Kholodov, Yu. A. "Voprosy gematologii, radiobiologii i biologicheskogo deystviya magnitnykh poley" [Questions in Hematology, Radiobiology and the Biological Effect of Magnetic Fields], Tomsk, 1965, p 342.

5. Asabaev, Ch.; Chernomorchenko, S. G. In: "Magnitnyye polya v meditsine" Frunze, 1974, p 16.

6. Borodkina, A. G.; Nakhil'nitskaya, Z. N. Ibid, p 77.

7. Bresler, S. Ye. PRIRODA, No 3, 1977, p 68.

8. Bruns, S. A.; Klassen, V. I.; Konoshina, V. I., Kolloyon, Zh, No 1, 1966, p 153.

9. Vardanyan, V. A. BIOFIZIKA, No 3, 1973, p 491.

10. Vasil'yev, N. V. In: "Magnitnoye polye v meditsine", Frunze, 1974, p 10.

11. Vasil'yev, N. V.; Shternberg, I. B.; Boginach, L. F. In "Vliyaniye magnitnykh poley na biologicheskiye ob"ekty" [The Influence of Magnetic Fields on Biological Subjects], Moscow, 1971, p 108.

12. Vinichenko, E. V.; Tyun'kov, I. V. In "Magnitnoye pole v meditsine," Frunze, 1974, p 81.

13. Voytinsky, Ye. Ya; Gendel's, B. S.; Gol'tsman, B. I. et al In "Magnitnoye pole v meditsine," Frunze, 1974, p 21

14. Gorshchenina, T. I.; Frumkis, A. E. Ibid, p 84.

15. Demetskiy, A. M.; Surganeva, S. F. Ibid, p 86.

16. Dorfman, Ya. G. In "Vliyaniye magnitnikh poley na biologicheskiye ob"ekty", Moscow, 1971, p 15.

17. Ir'yanov, Yu. M. "Deystvie magnitnogo polya na nervnuyu sistemu" [The Influence of the Magnetic Field on the Nervous System], abstract of Master's thesis, Perm', 1971.

18. Kikut, R. P.; Nilolayev, D. D.; Millere, L. A. In "Primeneniye magnitnykh poley v klinike" [Application of Magnetic Fields in Clinical Medicine], Kuybyshev, 1976, p 43.

19. Kikut, R. P.; Kalnber, V. K.; Liyepa, M. E. Ibid, p 141.

20. Kliment'yeva, N. A.; Garganeyev, G. P. In "Magnitnoye pole v meditsine," Frunze, 1974, p 87.

21. Kornatovskiy, Ya. I.; Zhulkevich, V. L.; Kostnykh, I. M. et al. In "Primeneniye magnitnykh polye v klinike," Kuybyshev, 1975, p 51.

22. Laptin, V. I. ; Pshenichnyy, I. P. Ibid, p 110.

23. Maryutin, V. I.; Dvorovenko, V. K. Ibid, 1974, p 89.

24. Merkulova, L. M.; Amosova, V. V. Ibid, p 91.

25. Minenko, V. I.; Petrov, S. M.: Mints, M. N. "Magnitnaya obrabotka vody" [Magnetic Treatment of Water], Khar'kov, 1962.

26. Nasonov, D. N. "O prirode vozbuzhdeniya" [The Nature of Stimulation], Moscow, 1948.

27. Pavlovich, S. A. In "Vliyaniye magnitnykh poley na biologicheskiye ob"ekty," Moscow, 1971, p 41.

28. Pel'ts, D. G.; Grigor'yev, N. R.; Dutov, D. G.; et al In "Magnitnoye pole v meditsine," Frunze, 1974, p 94.

29. Presman, A. S. "Elektromagnitnyye polya i zhivaya priroda," [Electromagnetic Fields and Nature], Moscow, 1965.

30. Razykov, S. R.; Abullakhodzhaeva, M. S. In "Magnitnoye pole v meditsine," Frunze, 1974, p 35.

31. Rusyayev, V. F.; Arsent'yev, Yu. A. In "Primeneniye magnitnykh poley v klinike," Kuybyshev, 1976, p 70.

32. Savostin, P. V. TRUDY MOSKOVSKOGO DOMA UCHENYKH, No 1, 1937 p 111.

33. Setlow, R.; Pollard, E. "Molekulyarnaya biofizika" [Molecular Biophysics], Moscow, 1964.

34. Sulenov, K. Zh. In "Magnitnoye pole v meditsine," Frunze, 1974, p 159.

35. Speranskiy, A. P.; Svyatenko, Ye. S.; Matyushkin, V. A.; et al NAUCH TRUDY TsENTRAL'NOGO IN-TA USOVERSHENSTVOVANIYA VRACHEY, Vol 200, 1976, p 53.

36. Toroptsev, I. V. ARKh.PAT., No 3, 1968, p 3.

37. Toroptsev, I. V.; et al. In "Vliyaniye magnitnykh poley na biologicheskiye ob"ekty," Moscow, 1971, p 93.

38. Toroptsev, I. V.; Garganeyev, G. P. In "Magnitnoye pole v meditsine," Frunze, 1974, p 8.

39. Umanskiy, D. M. Zh. TEORET FIZIKA, Vol 35, 1965, p 2245.

40. Kholodov, Yu. A. "Vliyaniye elektromagnitnykh poley na tsentral'nuyu nervnuyu sistemu," Moscow, 1966, p 260.

41. Kholodov, Yu. A.; Buvan, G. N.; Berlin, Yu. V. In "Magnitnoye pole v meditsine," Frunze, 1974, p 12.

42. Kholodov, Yu. A. In "Vsesoyuznyy s"ezd fizioterapevtov i kurortologov. 7-y. Materialy" [Materials of the Seventh All-Union Conference of Physical Therapists and Health Resort Physicians], Moscow, 1977, p 243.

43. Shishlo, M. A. In "Vliyaniye magnitnykh poley na biologicheskikh ob"ekty", Moscow, 1971, p 24.

44. Shepetil'nikova, A. I. In "Magnitnoye pole v meditsine," Frunze, 1974, p 162.

45. Barnothy, J. M. MED. PHYS., Vol 3, 1960, p 61.

46. Barnothy, J. M. NATURE, Vol 193, 1962, p 1243.

47. Barnothy, M. F. Ibid, Vol 200, 1963, p 279.

48. Barnothy, M. F. In "Biological Effects of Magnetic Fields," Vol 1, New York, 1964, pp 80-89.

49. Barnothy, M. F., Barnothy, J. M. NATURE, Vol 225, 1970, p 1146.

50. Bellossi, A.; Bresson, V., de Certaines, J. C. R. SOC. BIOL., Vol 165, 1971, p 1503.

51. Bellossi, A.; Michon, J.; de Certaines, J. BULL. SOC. MED. AFR. NOIRE LANGUE FRANC., Vol 20, 1975, p 269.

52. Bellossi, A.; Duclos, M.; Bellossi, G. Ibid, Vol 19, 1974, p 192.

53. Bellossi, A.; Michon, J. Ibid, Vol 20, 1975, p 266.

54. Gardner, W. A.; Grossi, C. E.; Rousselot, L. M. CLIN. RES., Vol 15, 1967.

55. Gleichman, von O. ERFAHRUNGSHEILKUNDE, Vol 25, 1976, p 105.

56. Gross, L.; Smith, L. W. FED. PROC., Vol 20, 1961, p 164.

57. Gross, L. NATURE, Vol 195, 1962, p 662.

58. Kerrington, A.; Mak-Lechlan, E. "Magnitnyy rezonanc i ego primeneniye v khimii" [Magnetic Resonance and its Application in Chemistry], Moscow, 1970.

59. Pelyhe, I.; Meszaros, I.; Sarvari, E. ACTA PHYSIOL. ACAD. SCI. HUNG., Vol 43, 1973, p 125.

60. Hackel, E.; Smith, A. E.; Montgomery, D. J. In "Biological Effect of Magnetic Fields," Vol 4, New York, 1964, p 218.

61. Valentinizzi, M. CIENC. E INVEST., Vol 16, 1960, p 250.

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SURVEY ARTICLE ON NIEMR RESONANCE PHENOMENA

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[Article by A. Z. Smolyanskaya, E. A. Gel'vich, M. B. Golant, and A. M. Makhov, USSR Academy of Medical Sciences Scientific Center of Oncology: "Resonance Phenomena Accompanying the Action of Electromagnetic Waves in the Millimeter Range on Biological Objects"]

[Text] Resonance phenomena accompanying the action of electromagnetic waves of nonthermal intensity on cells and multicellular organisms are examined. Some theoretical conceptions pertaining to the mechanism of action of an electromagnetic field on biological objects are discussed.

A number of data have recently been obtained attesting to the possibility that electromagnetic waves with quantum energy of about 10^{-4} ev may have a resonant action upon biological objects. These effects are very strongly dependent on the emission frequency, and they are observed in the presence of low power flux densities, at which thermal effects are not manifested.

It should be noted that this action may be directed at strictly differentiated functions of the cell or of a multicellular organism, which is of both practical and theoretical interest.

Resonant Effect of Superhigh-Frequency Emissions on Biological Objects. Dependence of Biological Effects on Emission Frequency

Effect of Emissions on Cell Division

The bulk of the papers dealing with the action of electromagnetic waves in the millimeter range are associated with cell division, with both stimulatory and suppressive action being noted. Thus waves in the 7.1-7.2 range (42.25-41.64 GHz) inhibited reproduction of Clostridium sporogenes, Clostridium histolyticum, and Bacterium prodigiosum (12). The maximum effect was observed in response to emissions with a wavelength of 7.15 mm (41.93 GHz). The authors note a weakly pronounced frequency dependence. Experiments with Rhodotorula rubra revealed that millimeter waves can both stimulate

and inhibit division of this culture (7). Emissions at 7.18 mm (41.75 GHz) accelerated growth by about 1.3 times; when the wavelength was changed by 0.005 mm in either direction the effect disappeared--that is, the critical increment of the effect in relation to wavelength was 0.005 mm. Growth intensity was observed to be inhibited at 7.16, 7.17, and 7.19 mm (correspondingly 41.87, 41.81, and 41.70 GHz). Comparing these works, we can note that 7.18 mm emissions have different effects on cell division, which may apparently be the product of unique features of the structures and biochemical reactions participating in these processes.

Ostapenkov et al. (17) observed stimulation of multiplication of *Bacterium mesentericus* by three times (39.5 GHz, 7.60 mm) and of *Pseudomonas fluorescens* by four times (39.45 GHz, 7.61 mm). It may be hypothesized that the inconsistency in the frequencies that intensify division is associated with differences in biochemical processes governing the vital activities of these species of bacteria. However, emissions with a frequency of 39.55 GHz (7.58 mm) suppress growth in both cultures--by 40 percent in the first and by 30 percent in the second. The sensitivity of the effect in relation to frequency was < 0.05 GHz (in relation to wavelength, < 0.01 mm).

Analysis of the influence of millimeter waves in the 64-76 GHz frequency range (4.68-3.94 mm) on division of *Escherishia coli* strain B_R revealed that emissions of 66, 71, 71.5, and 73 GHz (4.54, 4.22, 4.19, and 4.11 mm) inhibit growth while 68 GHz (4.41 mm) stimulates it (45). The authors suggest that inhibition and stimulation of cell division are associated with the action of electromagnetic waves on cell metabolism. It was demonstrated that emissions with a frequency of 66 GHz inhibit assimilation of thymine and amino acids by cells. And inasmuch as protein does not absorb waves of this frequency (see below) the action on emissions is associated with the protein synthesis mechanism indirectly. Waves with a frequency of 71 GHz significantly reduce assimilation of all labeled metabolites, 71.5 GHz waves somewhat suppress accumulation of thymine and amino acids, and 73 GHz waves correspond to the maximum of protein absorption. They all inhibit cell growth. Assimilation of uracil-^{14}C is stimulated and amino acid accumulation is somewhat intensified when cells are irradiated by a frequency of 68 GHz. In this case cell proliferation intensifies, but thymine assimilation does not change. The action of millimeter waves on cell metabolism is confirmed by data in (16).

Electromagnetic waves in the 41-42 GHz range (7.32-7.14 mm) both suppress and stimulate multiplication of yeast. The critical level of resonant lines attained 10 MHz in these experiments (32). Emissions with a wavelength of 6.5 mm (46.12 GHz) additionally elicited morphological changes such as rupture of cell membranes, degeneration of protoplasm, and enlargement of cell dimensions and the concentration of DNA, RNA, and protein (11). Emissions in the 7-116 GHz range (42.83-2.58 mm) stimulated cell growth in a culture of *E. coli* strain B. In this case the effect manifested itself especially distinctly in the growth inhibition phase (by an increase of almost twice). The authors suggest that this effect is associated with

intensification of substrate transport and ATP synthesis (40). On the other hand millimeter waves were also noted to have an inhibitory action on division of *E. coli* (9). Maximum inhibition was detected in response to irradiation by waves with a length of 6.5 mm (46.12 GHz).

Inhibition of growth of *E. coli* strain K12 was observed in response to irradiation in the 70-75 GHz range (4.28-3.97 mm). Maximum action was manifested at 70.5 and 73 GHz (4.25 and 4.11 mm) at a power flux density of 10 mw/cm^2 (27). In this case millimeter waves were not observed to have a mutagenic effect on *E. coli* strain tryp$^-$ and *Saccharomyces cerevisiae* strain his$^-$ (24,27).

Analysis of the effect of electromagnetic waves in the 6.3-6.9 mm range (47.59-43.45 GHz) on microflora in the air of a certain laboratory demonstrated that they have bactericidal action exhibiting a weakly pronounced frequency dependence (1). The maximum effect was observed at wavelengths from 6.5 to 6.6 mm (from 46.12 to 45.42 GHz). Acutely resonant phenomena were not observed, possibly because the experiment was performed with large intervals between the frequencies studied. We may add that due to the absence of active metabolism by bacteria suspended in the air, the action of millimeter waves was not associated with cell processes--that is, it was not biological in nature, being instead the product of polarization of bacterial structures coupled with the consequent electrostatic effects.

Summarizing the above, we can conclude that millimeter emissions of nonthermal intensity influence cell division, having both stimulatory and inhibitory action.

Different species of bacteria, and apparently even individual strains have their individual series of resonant frequencies eliciting such phenomena, ones that may be of both the same and different sign in response to electromagnetic waves of the same wavelength. At the present stage of the research it is difficult to answer the question as to what structures or biochemical processes are effected by millimeter emissions, and as to how they stimulate and inhibit cell division. We can only hypothesize that such emissions elicit changes in the conformation of individual molecules or their complexes.

Action of Millimeter Waves on Processes Regulating the Functional Activity of Some Bacterial Systems

When colicinogenic *E. coli* strain C600 (Col E1) is irradiated by millimeter waves with wavelengths of 5.8, 6.5, 6.53, 6.59, and 7.1 mm (51.17, 46.12, 45.91, 45.77, 45.49, and 42.23 GHz) the relative quantity of cells synthesizing colicin increases by 2.5-4 times. At the same time irradiation by waves of intermediate length did not have a noticeable influence on these cells (3,23). The sensitivity of the effect in relation to wavelength attained 0.02 mm.

Millimeter waves were found to have similar action on *Staphylococcus aureus* lysogenic strain No 962. When irradiated by 6.5 mm electromagnetic waves (45.79 GHz), the phage yield increased by 2.2 times. The sensitivity of the effect in relation to wavelength attained 0.005 mm. Irradiation by waves with lengths of 6.52 and 6.56 mm (45.98 and 45.70 GHz) led, according to data obtained in our laboratory by A. V. Suslov, to a decline in phage yield in comparison with a spontaneous background.

Millimeter waves having resonant action were also described to have phage-inducing action (11). The maximum effect was observed at a wavelength of 6.5 mm. The quantity of phage particles increased by four times in comparison with the spontaneous phage yield. The noted differences in wavelengths inducing growth of the prophage are apparently associated with differences in the objects analyzed. It is entirely possible that phenomena of similar biological meaning are observed in species of bacteria differing from one another when the latter are irradiated by electromagnetic waves of different lengths.

According to our data from research on the action of millimeter waves on synthesis of penicillinase by *Staph. aureus* No 469 and *E. coli* No 7, exposure to waves with lengths of 6.468 and 6.478 mm (46.35 and 46.34 GHz) inhibits inducible synthesis of the enzyme by *Staph. aureus*, without having an influence on constitutive synthesis and without changing the activity of penicillinase itself (the exoenzyme was studied). The dependence of the inhibitory effect is acutely resonant: When the wavelength is changed by $\pm$ 0.005 mm, the inhibitory effect disappears. When the cell concentration is decreased by 10 times the magnitude of the effect increases by four times (wavelength 6.478 mm, irradiation time 1.5 hours).

A number of authors (3,11,23) demonstrated that electromagnetic emissions in the millimeter range may significantly influence inducible processes, activating or inhibiting functional activity of genetic elements in bacterial cells responsible for this function. This action is highly specific (unique active wavelengths are typical of each object), and it is sensitive to change in wavelength (to 0.005 mm).

Revelation of the inducing action of millimeter waves and the resonant nature of this influence have fundamental significance to conclusions concerning the fine mechanisms of induction of the functional activity of some genes, and on the biological significance of electromagnetic radiation of nonthermal intensity operating as an inducing agent. It should be noted that DNA-tropism, or the pronounced capability for eliciting degradation of DNA or inhibiting its synthesis, is a property all inducing agents have in common. In this respect electromagnetic emissions in the millimeter range are a qualitatively new inducing agent, since their action cannot be associated with similar mechanisms in view of the low quantum energy. These emissions are highly selective in comparison with chemical inducing agents and ultraviolet emissions, in the sense that each biological system has its own induction frequency.

Action of Millimeter Emissions on Functionally Active Proteins

A large number of papers have been devoted to the effect of emissions on enzymes and, in particular, on hemoglobin. It was noted in experiments with dry samples that waves with a length of 7.2 mm (41.67 GHz) elicit stabilization of the haeme-protein bond, while waves with a length of 7.35 mm (40.79 GHz) weaken it (2,6). However, in aqueous solutions emissions with a frequency of 7.35 GHz make the bond stronger. The sensitivity of these effects in relation to wavelength is relatively low, being 0.2 mm. When samples are cooled, the effect is not manifested (5,14,18). The authors of these papers believe that changes in the active center or in kinetics upon transition of hemoglobin from the oxy- to the meta-form may be one of the possible mechanisms of action of millimeter radiation.

Emissions with wavelengths of 6.0, 6.2, 6.6, and 7.4 mm (49.97, 48.36, 45.42, and 40.54 GHz) intensify the fibrolytic activity of proteases in *Aspergillus oryzae* (AHLB)Coh N. Maximum intensification of activity was observed at wavelengths of 6.0, 6.2, and 6.6 mm; 6.5 mm waves caused inhibition. Waves in the 5-8 mm range raised the osmotic and acid resistance of erythrocytes. Emissions with a wavelength of 6.5 mm did not cause changes in the fractional concentration of the hemoglobin, but they did decrease the level of free hemoglobin in the supernatant (10).

Action of Millimeter Waves on Multicellular Organisms

Resonance phenomena are noted not only at the molecular and cellular levels but also in multicellular organisms. The fertility of *Drosophila* decreased in response to exposure to electromagnetic waves with lengths of 5.5, 6.5, and 7.2-7.3 mm (54.51, 46.12, and 41.64-41.07 GHz). Intensification of mutations was also noted. However, the question as to the mutagenicity of millimeter waves continues to be debatable. There are a number of data arguing both in favor of mutagenic action and against it. Millimeter emissions do not directly cause profound structural changes in the DNA molecule owing to low quantum energy in comparison with the bond energy within the molecule. Possibly the action of emissions upon mutagenesis is indirect, for example through disturbance of metabolism or through change in activity of enzymes associated with DNA replication or repair.

Millimeter waves have been described as having a protective action on the hemopoietic system, protecting it from injuries caused by roentgen rays. Preliminary exposure of mice to wavelengths of 6.7, 6.85, 7.09-7.16, 7.26, and 7.7 mm (44.75, 43.77, 42.29-41.87, 41.30, and 38.94 GHz) led to almost complete recovery of the total number of bone marrow cells subjected to destruction by roentgen rays. The effect was acutely resonant: When the wavelength was changed by 0.01 mm protection against roentgen rays was no longer observed. The mechanism of this phenomenon has still not been explained with sufficient clarity (20-22). It should be noted that this effect was also observed with *E. coli* K12 cells. The sensitivity of bacteria to roentgen rays varied in response to electromagnetic waves in the frequency

range from 70 to 75 GHz (24). Cell growth decreased at these frequencies, possibly due to reduction of the intensity of metabolic processes in the cell. On the other hand we know that substances which inhibit metabolic processes have protective action against ionizing emissions. Apparently millimeter waves are similar to chemical protectors, inhibiting bacterial metabolism and thus preventing radiation injury.

It has been suggested that millimeter emissions may be used to control insect pests (36). Adult specimens are the most sensitive to the action of waves, and the effectiveness of the latter depends on emission frequency. At a frequency of 39 GHz (7.69 mm) insect death is noted to be maximum. It is possible that the action of electromagnetic waves is oriented at some particular aspect of metabolic processes, altering their intensity and leading to lethal consequences.

Resonance Phenomena in Response to the Action of Electromagnetic Waves in the Centimeter Range on Biological Objects

Kulin et al. (15) studied the influence of electromagnetic oscillations in the 20-300 MHz range (15-1 dm) on the phagocytic action of *Paramecium*. And although the authors did not use the millimeter range, it is interesting to note that the reaction to irradiation had a pronounced resonant nature. Stimulation of the phagocytic function of *Paramecium* was noted at 25, 45, 50, 65, 105, 140, 257, and 260 MHz, while inhibition was observed at 115, 160, 230, and 263 MHz. The breadth of resonance lines varied from 1 to 4 MHz, the average breadth being 2 MHz. The authors associate the mechanism of action with polarization processes occurring in response to application of the electromagnetic field. However, such high sensitivity of the observed effects in relation to emission frequency sheds doubt on the validity of this assertion.

Research on the action of electromagnetic waves in the 2-10 MHz range on lipid metabolism in mice revealed that the rate of triglyceride formation increases at frequencies of 2.9, 5.4, 9.4 and (especially) 2.4 MHz. Thus the action of electromagnetic waves in this range is oriented, as is true with millimeter emissions, on metabolic processes (28).

Thus the action of electromagnetic waves on biological objects is highly sensitive to wavelength (frequency). In this case certain wavelengths, ones that are different in relation to different organisms, affect particular functions. In some cases the same wavelength influences different functions, which may be the result of similar processes and structures participating in these functions. In other cases electromagnetic radiation of the same wavelength has biological action of opposite nature (for example stimulation of division or its inhibition) in different organisms. This is also apparently associated with the specific nature of structures responsible for these functions.

Dependence of Biological Effects on the Power Flux Density of Millimeter Radiation

The dependence of the biological effect on power flux density was demonstrated most fully with colicinogenic *E. coli* C600 (E1) (4,23). When the power flux density was increased from 0.01 to 0.1 mw/cm^2 the effect increased and attained its maximum value, which did not change even at 10 mw/cm^2. This dependence is confirmed by the influence of millimeter waves on inducible synthesis of penicillinase by *Staph. aureus*. In most known projects conducted with microorganisms the power flux density did not exceed several units or fractions of mw/cm^2. In animal experiments the density at which resonance phenomena were observed was about 10 mw/cm^2. It should be noted that when a bacterial culture was irradiated with a power flux density of 100 mw/cm^2 for 15 minutes, lethal and mutagenic effects were not observed. The fact that quantitative stabilization of the biological effect (and the resonant nature of the effect in relation to frequency) occurred as a rule at power densities that could never be associated with any sort of thermal effect once again attests to the truly specific selective action of electromagnetic waves on biological objects.

Dependence of Biological Effects on Irradiation Time

It has been noted that biological effects taking the form of resonance phenomena are observed in response to rather prolonged exposure to millimeter waves. The minimum time after which any sort of functional changes could be detected in biological systems is about 15 minutes. Lengthening of the exposure time causes growth in the magnitude of the effect, stabilization occurring 1.5-2 hours after irradiation.

When *E. coli* C600 (E1) was irradiated for from 30 minutes to 1.5-2 hours the number of cells synthesizing colicin increased. Further growth in irradiation time did not elicit noticeable changes in induction (3). In research on the action of millimeter waves on penicillinase synthesis, the maximum biological effect was observed following 1.5 hours of irradiation. Longer irradiation times diminished the effect. The authors explained this dependence by laws of the enzyme-substrate reaction. It was demonstrated with the bacterial strain *E. coli* B that irradiation by electromagnetic waves with a frequency of 136 GHz (2.21 mm) for 1.5-2 and 1-1.5 hours did not lead to noticeable change in cell reproduction in cultures in their lac- or log-phase. When the irradiation time was increased to 6 hours the growth inhibition effect gradually intensified. By 6 hours, the number of cells in the unirradiated culture was six to seven times greater than in the irradiated culture (47). However, we cannot assert on the basis of these data that the action of millimeter waves is associated only with irradiation time. The time following which we detect any sort of functional changes depends on the sensitivity of the biological and physical methods employed. Unfortunately we do not as yet possess recording methods that are sensitive enough to instantaneously reveal changes in biological objects introduced into an electromagnetic field. Frohlich (29) suggests that the time required for

change to occur in the structure of a macromolecule to which an electromagnetic field is applied is 10^{-10} - 10^{-11} sec.

Superhigh-Frequency Spectroscopy of Biological Objects

This method has not attained broad application yet, but the data that have been obtained (be they few in quantity) are of significant interest. Research on absorption of millimeter waves by normal and tumor cells showed that an individual absorption spectrum exists for each type of tumor. A difference was noted in absorption, by tumor and normal cells, of electromagnetic waves in the 76-86 GHz (3.95-3.49 mm) (41) and 66-76 GHz (4.54-3.95 mm) (46) ranges. Tumor cells absorb millimeter waves with frequencies of 66, 68, and 70 GHz (4.54, 4.41, and 4.28 mm) more weakly than normal cells, and waves with frequencies of 69, 71, and 75 GHz (4.34, 4.22, and 4.00 mm) more strongly. A similar pattern is observed in research on absorption of waves having these frequencies by free DNA and RNA isolated from tumor and normal cells. Webb and Booth suggest that absorption in the 66-76 GHz range depends on the energy levels of rotation of water molecules forming a hydrate shell around the macromolecules. Forming hydrogen bonds with different groups in the DNA molecule, these water molecules can rotate freely, and transitions between energy levels must follow the rules of selection. Thus these authors associate absorption in the 66-68 GHz range with water adsorbed by the P = O group in DNA, and at 70 GHz with water adsorbed by the C - O - C or OH group of DNA. When guanosine undergoes phosphorylation absorption at 70 and 75 GHz weakens. Thus absorption at 66, 69, and 71 GHz stems from rotational transitions of water molecules bound to P = O groups in the DNA, while absorption at 70 and 75 GHz depends on OH groups in DNA phosphorylated upon formation of guanylic acid. The increase in absorption at 69, 71, and 75 GHz may be explained first by the greater quantity of DNA in tumor cells than in normal cells, and secondly by the different number of groups responsible for absorption, given an identical concentration of DNA and RNA. The authors suggest that tumor cells have fewer P = O groups and more C - O - P, C - O - C, and OH groups from sugars present in the cell as metabolites and structural elements of DNA and RNA. Thus differences in absorption of millimeter waves by normal and tumor cells are possibly dependent on presence of specific molecular groups or of an excess quantity of DNA and RNA fragments that may bond covalently with P = O groups in normal DNA.

Analysis of the superhigh-frequency spectrums of *E. coli* B cells (at 66, 68, 71, and 73 GHz) and of DNA (66 and 69 GHz), RNA (68 and 71.5 GHz), and protein (67, 70, 71.5, and 73 GHz) isolated from them showed that the maximums of absorption of waves with frequencies of 66, 68, and 73 GHz (4.54, 4.41, and 4.11 mm) are identical to the maximums for DNA, RNA, and protein respectively (45). The degree to which cells absorb waves of these frequencies corresponds approximately to the relative concentration of these three types of molecules. Absorption maximums were not observed in the cell spectrums for protein and DNA at 67 and 69 GHz (4.58 and 4.34 mm) respectively. Apparently the molecular or group energy levels responsible

for absorption of waves at these frequencies by isolated structures are absent from intact cells. This may be the result of formation of macromolecular complexes between protein and DNA in the cells. These phenomena are possibly also typical of absorption of 71.5 GHz (4.19 mm) waves by protein and RNA. It should be noted that the spectrum of electromagnetic wave absorption for water at 69, 71.5, and 73.7 GHz presented in this work is rather difficult to explain, since water does not exhibit resonant absorption in this range. This suggests the notion that errors may have been made in the measuring technique.

The absorption spectrum of normal and tumor cells differ in the 500-200 GHz (6.0-1.5 mm) range, in which case each type of cells may form from two to four successions of frequencies (44). These superhigh-frequency spectrums possibly reflect fundamental differences in distribution of the energy of possible transitions between the states assumed by structural formations in cells *in vivo*. Some of these energy levels may be interpreted as spectral lines of forced combined light scattering (49). It has been hypothesized that millimeter waves with frequencies greater than 50 GHz are capable of preventing manifestation of certain vitally important processes by specific nonthermal action *in vivo* (44,48).

Thus there are grounds for suggesting that the methods of microwave spectroscopy and combined light scattering spectroscopy will subsequently serve as tools for studying resonant interactions between electromagnetic fields and biological objects.

Possible Mechanisms of the Resonant Action of Electromagnetic Fields on Biological Objects

These methods have been examined most fully by Berteaud (26). The author suggests that the action of the magnetic component of electromagnetic radiation is associated with the diamagnetic or paramagnetic orientation of molecules. The electric component may govern movement of free charges and cause induced polarization or orientation of molecules with a constant dipole moment in the direction of the electric field. The phenomena enumerated above depend on the structure of the elements, viscosity, medium temperature, and (to a minor extent) frequency, and they are not characterized by the high sensitivity to change in wavelength (frequency) manifested in biological effects.

Electromagnetic waves may elicit mechanical effects. Mechanical forces arise in a nonuniform field if a particle with dielectric permeability ε_2 is present in a solution having dielectric permeability ε_1. And if in the absence of this particle an unperturbed field E_0 is applied to the solution, introduction of the particle would cause (according to the theory of minor perturbations) a potential energy ΔU:

$$\Delta U = \frac{1}{2} \int_{v_1} (\varepsilon_2 - \varepsilon_1) E_1 E_0 dv.$$

where v_i is the particle volume and E_i is the effective field in the particle. For a uniform isotropic medium and spherical particle,

$$E_i = \frac{3\varepsilon_2}{\varepsilon_1 + 2\varepsilon_2} E_0.$$

Hence

$$\Delta U = \frac{3}{2} \int \varepsilon_2 \frac{\varepsilon_2 - \varepsilon_1}{\varepsilon_1 + 2\varepsilon_2} E_0^2 dv.$$

The particle is acted upon by the force

$$F = -\frac{3}{2} V_p \varepsilon_2 \frac{\varepsilon_2 - \varepsilon_1}{\varepsilon_1 + 2\varepsilon_2} \operatorname{grad} E_0^2$$

or $F = -\operatorname{grad} (\Delta U)$. Force F is proportional to the degree of nonuniformity of the field, particle volume, and a function expressing the difference in the electric properties of the medium and particle. An electric field with a higher intensity gradient of about 10^4 w/cm would be needed to cause movement of particles with dimensions of about 1μ. The orientation of particles devoid of spherical symmetry is similar in an electromagnetic field to the orientation, described above, of spherical particles in the direction of the intensity vector of the electric field.

Formation of chains out of particles suspended in a liquid medium is also a mechanical effect. It has been suggested that in this case a nonuniformity in the field at the location of, for example, particle B stems from summation of field E_0 (uniform) and bipolar field E_A (always nonuniform), characterizing the action of particle A on particle B. On analogy with the first case, the particle's potential energy is

$$\Delta U = V_B \varepsilon_2 \left| \frac{\varepsilon_2 - \varepsilon_1}{\varepsilon_1 + 2\varepsilon_2} \right|^2 \cdot E_0^2 f(r, \theta),$$

where $f(r,\theta)$ is a function depending on the polar coordinates of A relative to B, and V_B is particle volume.

Particles form chains (ir such as this leads to a decrease in potential energy) when ΔU exceeds thermal energy kT. Field E_s, corresponding to the equality $\Delta U = kT$, is defined as

$$E_s = Ca^{-\frac{3}{2}} \left(\frac{\varepsilon_1 + 2\varepsilon_2}{\varepsilon_2 - \varepsilon_1} \right) \cdot \sqrt{\frac{kT}{\varepsilon_2}}.$$

where C is a constant depending on $f(r,\theta)$, and a is particle dimension. The expression for E_s shows that the field varies as a function of $a^{-3/2}$. The experimental data confirm the dependence of E_s on a for particles with dimensions from 0.7 to 7μ. It has also been demonstrated that at up to 100 MHz, E_s does not depend on frequency (26).

Orientation of polarized particles in response to the action of an electromagnetic field has been examined in a number of other works (31,33,35,39). These authors suggest that owing to chain formation the secondary and tertiary structures of molecules may break down, hydrogen bonds may rupture, and other similar effects may occur.

Summarizing the above, we can say that mechanical effects do not apparently play a significant role in resonance phenomena. This is confirmed by both experimental data and theoretical computations. Field intensity and the state of the medium and the particles have a significant role in arisal of mechanical phenomena.

According to Rabinowitz (37) electromagnetic fields act upon: the state of the magnetic and electric nucleus-electron bond, which depends on interaction between the nuclear quadrupole moment and the molecule's distributed charge; free rotation states of molecules; limited mobile states of molecular segments.

Let us examine the action of an electromagnetic field on free rotation states of molecules, which are a function of molecular mass distribution. In this case the interactions within the structure of the molecule do not undergo change, but the kinetic energy of rotation increases. This effect of electromagnetic waves has an influence on biological systems, inasmuch as it leads first to an increase in the system's local kinetic energy and then (as a result of collisions) in the system's total kinetic energy. This should mean a rise in the temperature of the biological system, which is not observed with resonance phenomena. On the other hand a certain increase in the temperature of biological objects does not lead to effects typical of resonance phenomena. And because this influence has as its end result an increase in the total kinetic energy of the system, we can hypothesize that it could hardly exhibit the high selectivity and acutely resonant effect observed in relation to electromagentic fields in the millimeter range.

The most probable mechanism of action of electromagnetic waves upon biological objects is that associated with limited rotations experienced by molecular segments. Possessing only a covalent bond, parts of molecules varying in size from OH groups to amino acids may rotate freely within macromolecules. The orientation of these parts relative to the rest of the molecule is governed by a weak potential of electrostatic interaction between the segments and the surrounding medium (usually the rest of the molecule). Moreover the low frequency of collisions within large molecules governs the probability of multiple excitations and structural changes in the macromolecule elicited by the latter. Such interactions may be acutely resonant, since rotational transitions between discrete energy levels in the molecular segments occur at strictly defined frequencies of electromagnetic radiation, assuming that the conditions of energy quantization and the selection rules are satisfied.

Theoretical computations performed with the objective of estimating the frequency of rotational transition for histidyl E7 in a hemoglobin molecule

interpreted as a rigid rotator showed that this transition may occur in the millimeter range (13).

Frohlich (29,30) suggests that biological molecules shift into a metastable state in response to the action of microwave emissions, which results in a change in their functional activity.

It is also possible that intermolecular interactions may be the product of electromagnetic waves in the microwave range, which makes them highly specific and selective (30,34).

Some authors associate the effect of microwave emissions with dipole-dipole interaction in enzyme molecules caused by fluctuations of protons in the molecule (19,43), or with uncoiling of the protein α-helix (25).

Thermal action is viewed as the result of intensified oscillation of ions in an electromagnetic field; these ions transmit this energy to molecules, which subsequently causes general heating of the object (38).

According to Tomberg (42) electromagnetic waves with an intensity of 10 mw/cm^2 produce a temperature gradient that attains 10° in some suspensions. However, Schwan and Piersol (1954) assert that selective heating of suspended particles may be observed only in the event that their diameter is less than 1 mm.

We can note in conclusion that the most acceptable explanation for resonant and acutely resonant effects in biological systems can be found in the action of microwave electromagnetic waves on the rotational states of molecular segments. This action is capable of altering the structure of individual parts of the macromolecule, and of influencing its overall conformation. However, most papers devoted to the behavior of biological objects in electromagnetic fields pay no attention to the high sensitivity the effects exhibit to change in wavelength (frequency).

Conclusion

In recent years a number of authors have observed the resonant and acutely resonant nature of the specific (nonthermal) action of millimeter waves on biological objects; this action is typified by extremely high sensitivity of biological effects to change in wavelength, attaining values less than 0.005 mm in certain experiments. In cases where such action was not observed and only individual active or neutral points and segments of the range were distinguished, the continuous frequency spectrum was not subjected to systematic analysis. As we can see from the published sources, this can be explained either by unavailability of broad-band superhigh-frequency oscillators, or by low resolution of the measuring apparatus, which prevents detection of acutely resonant effects.

The specific action of millimeter emissions upon biological objects differs from the action of ionizing radiation in that the observed effects are extremely weakly dependent on power flux density: The latter may vary by several orders of magnitude without changing the effects.

This dependence of biological effects on radiation frequency and power flux density confirms the nonthermal (specific) nature of the action, which is not associated with direct heating of the object. In cases where slight changes in temperature (1-2°) were recorded in response to irradiation, the nature of the dependencies indicated above remained as before, and consequently heating was not the dominant factor in the action.

The isolated hypotheses or reports that have been published concerning the specific action of electromagnetic fields on biological objects permit us to state, for the moment, only the general conclusion that the conformation of complex biological molecules introduced into an electromagnetic field with an extremely low quantum energy may possibly change.

BIBLIOGRAPHY

1. Adamenko, V. G., Vilenskaya, R. L., Golant, M. B., Kiryushina, I. N., and Shustrova, A. Ya., ELEKTRONNAYA TEKHINIKA, VYP. "ELEKTRONIKA SVCH," No 12, 1966, p 132.

2. Andreyeva, A. P., Dmitriyeva, M. T., Il'ina, S. A., Koreneva, L. G., Kudryashova, V. A., Merzlov, V. P., and Faleyev, A. S., ELEKTRONNAYA TEKHNIKA, VYP. "ELEKTRONIKA SVCH," No 11, 1971, p 121.

3. Vilenskaya, R. L., Smolyanskaya, A. Z., Adamenko, V. G., Buldasheva, Z. P., Gel'vich, E. A., Golant, M. B., and Gol'dgaber, D. A., BYUL. EKSPERIM. BIOL. I MED., Vol 4, 1972, p 52.

4. Vilenskaya, R. L., Smolyanskaya, A. Z., Gel'vich, E. A., and Golant, M. B., NAUCHN. DOKL. VYSSH. SHKOLY. BIOL. NAUKI, Vol 7, 1972, p 69.

5. Gayduk, V. I., Khurgin, Yu. I., and Kudryashova, V. A., USPEKHI FIZ. NAUK, Vol 110, 1973, p 466.

6. Devyatkov, N. D., ELEKTRONNAYA TEKHNIKA, VYP. "ELEKTRONIKA SVCH", Vol 4, 1970, p 130.

7. Devyatkov, N. D., USPEKHI FIZ. NAUK, Vol 110, 1973, p 453.

8. Yegorov, N. S., Golant, M. B., Landau, N. S., Okhokhonina, G. M., Sycheva, N. A., and Bryukhova, A. K., MIKOL. I FITOPATOL., Vol 11, 1977, p 303.

9. Zalyubovskaya, N. P., USPEKHI FIZ. NAUK, Vol 110, 1973, p 462.

10. Zalyubovskaya, N. P., Kiselev, R. I., Prikhod'ko, Ye. P., and Gordiyenko, O. I., in "Eksperimental'naya i klinicheskaya radiologiya" (Experimental and Clinical Radiology), Khar'kov, Vol 11, 1975, p 75.

11. Kiselev, R. I., and Zalyubovskaya, N. P., USPEKHI FIZ. NAUK, Vol 110, 1973, p 464.

12. Kondrat'yeva, V. F., Chistyakova, Ye. N., Shmakova, I. F., Ivanova, N. B., and Treskunov, A. A., USPEKHI FIZ. NAUK, Vol 110, 1973, p 460.

13. Koreneva, L. G., and Gayduk, V. I., DOKL. AN SSSR, Vol 193, 1970, p 465.

14. Kudryashova, V. A., Il'ina, S. A., Fadeyev, A. S., Gayduk, V. I., and Dementiyenko, V. V., in "IV vsesoyuzn. simpoz. 'Gigiyena truda i biologicheskoye deystviye elektromagnitnykh voln. radiochastot'" (Fourth All-Union Symposium "Labor Hygiene and the Biological Action of Electromagnetic Radio-Frequency fields"), Moscow, 1972, p 64.

15. Kulin, Ye. T., Demidova, S. I., and Kasimenko, V. B., BIOFIZIKA, Vol 13, 1968, p 81.

16. Manoylov, S. Ye., Chistyakova, Ye. N., Kondrat'yeva, V. F., and Strelkova, M. A., USPEKHI FIZ. NAUK, Vol 110, 1973, p 461.

17. Ostapenkov, A. M., Matison, V. A., Belovolov, A. V., and Lavrova, V. L., IZV. VYSSH. UCHEBN. ZAVEDENIY. PISHCHEVAYA TEKHNOLOGIYA, Vol 1, 1976, p 77.

18. Polukhin, A. T., Il'ina, S. A., and Kudryashova, V. A., "Computation of the Action of Low-Power High-Frequency Electromagnetic Emissions on Some Partially Free Bonds in the Hemoglobin Molecule," Preprint from the USSR Academy of Sciences Institute of Electronics, No 120, Moscow, 1972.

19. Presman, A. S., USPEKHI SOVREMEN. BIOL., Vol 56, 1969, p 5.

20. Sevost'yanova, L. A., and Vilenskaya, R. L., USPEKHI FIZ. NAUK, Vol 110, 1973, p 456.

21. Sevost'yanova, L. A., and Vilenskaya, R. L., NAUCH. DOKL. VYSSH. SHKOLY. BIOL. NAUKI, Vol 6, 1974, p 48.

22. Sevost'yanova, L. A., Potapov, S, L., Adamenko, V. G., and Vilenskaya, R. L., NAUCH. DOKL. VYSSH. SHKOLY. BIOL. NAUKI, Vol 6, 1969, p 46.

23. Smolyanskaya, A. Z., and Vilenskaya, R. L., USPEKHI FIZ. NAUK, Vol 110, 1973, p 458.

24. Averback, D., Dardalhon, M., and Berteaud, A. J., J. MICROWAVE POWER, Vol 11, 1976, p 143.

25. Bach, S. A., Luzzio, A. J., and Brownell, A. S., J. MED. ELECTRON., Vol 1, No 1, 1961, p 9.

26. Berteaud, A. J., J. ELECTRON AND FIS. APPL., Vol 16, 1973, p 517.

27. Berteaud, A. J., Dardalhon, M., Rebeyrotte, N., and Averbeck, D., C. R. ACAD. SCI. D, Vol 281, 1975, p 843.

28. Deficis, A., Dumas, J. C., Laurens, S., and Plurien, G., J. MICROWAVE POWER, Vol 11, 1976, p 137.

29. Frohlich, H., NATURE, Vol 228, 1970, p 1093.

30. Frohlich, H., PHYS. LETTERS, Vol 39A, 1972, p 2.

31. Furedi, A., and Valentine, R., BIOCHIM. ET BIOPHYS. ACTA, Vol 56, 1962, p 33.

32. Grundler, W., Keilman, F., and Frohlich, H., PHYS. LETTERS, Vol 62A, 1977, p 463.

33. Heller, J., and Texeria-Pinto, A. A., NATURE, Vol 183, 1959, p 905.

34. Holland, V. W., J. THEOR. BIOL., Vol 35, 1972, p 395.

35. Kolant, W., CANAD. MED. ASSOC. J., Vol 81, 1959, p 575.

36. Nelson, S. O., and Stetson, L. V. E., INST. ELECTRIC AND ELECTRON ENGNG. TRANS. MICROWAVE THEORY AND TECHN., MTT-22, 1974, p 1303.

37. Rabinowitz, J., INST. ELECTRIC AND ELECTRON. ENGNG TRANS. MICROWAVE THEORY AND TECHN., MTT-21, 1973, p 850.

38. Schliephake, E., MUNCHNER MED. WOCHENSCHR., Vol 104, 1962, p 1238.

39. Schwan, H. P., in "Proc. 2nd annual Tri-service conf. biol effects microwave energy," Charlottesville, Univ. Virginia Press, 1958, p 53.

40. Seto, Y. J., and Hsieh, S. T., "Proc. 28th annual conf. eng. med. and biol.," New Orleans, Vol 17, 1975, p 208.

41. Stamm, M. E., Winters, W. D., Morton, D. L., and Warren, S. L., ONCOLOGY, Vol 29, 1974, p 291.

42. Tomberg, W., in "Biological Effects of Microwave Radiation," New York, Plenum Press, Vol 1, 1961, p 211.

43. Vogolhut, P. O., in "Pro: 3rd Internat. Conf. Med. Electron," London, 1960, p 52.

44. Webb, S. J., J. MICROWAVE POWER, Vol 11, 1976, p 138.

45. Webb, S. J., and Booth, A. D., NATURE, Vol 222, 1969, p 1199.

46. Webb, S. J., and Booth, A. D., SCIENCE, Vol 174, 1971, p 72.

47. Webb, S. J., and Dodds, D. D., NATURE, Vol 218, 1968, p 374.

48. Webb, S. J. and Stoneham, M. E., PHYS. LETTERS, Vol 60A, 1977, p 267.

49. Webb, S. J., Stoneham, M. E., and Frohlich, H., PHYS. LETTERS, Vol 63A, 1977, p 407.

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INFLUENCE OF A LOW FREQUENCY (50 Hz) ELECTRIC FIELD ON THE ORGANISM

Moscow GIGIYENA I SANITARIYA in Russian No 1, 1979 pp 11-15

[Article by R. D. Gabovin and I. P. Kozyarin, of the Kiev Medical Institute imeni Academician A. A. Bogomolets]

[Text] For purposes of hygienic evaluation of electric fields of industrial frequency formed by ultrahigh-voltage transmission lines (?30 to 750 kV), a survey was conducted by interviewing members of the popula ion living near such lines. Generalized materials of the survey showed that persons living near, passing or performing any sort of work under power transmission lines can be provisionally divided into three groups: group 1 includes persons exposed to the action of electric fields of industrial frequency daily for over 12 hours, group 2 those exposed to the action for 2 hours, and group 3 those exposed to the action for 30 minutes. Ye. V. Prokhvatilo has shown that after 4 months of daily exposure for over 12 hours per day the threshold intensity of electric fields of industrial frequency is 1 kV/m, and the subthreshold is 0.5 kV/m. That intensity has been proposed as the maximum allowable level for the conditions of inhabited places.

I. P. Kozyarin has established that during the action of an electric field of industrial frequency of up to 2 hours per day the threshold intensity is 7 kV/m and the maximum allowable intensity is 5 kV/m.

The present paper presents the results of investigations conducted on animals for the same purpose during a 30-minute daily action of electric fields of industrial frequency. The biological model consisted of male white rats with an initial mass of 120-130 g that were placed in a special cell with a modeled electric field with a frequency of 50 Hz, formed by high-voltage oil transformers. Rats of group 1 served as the control and the animals of groups 2, 3 and 4 were exposed daily for 4 months to the 30-minute action of an electric field of industrial frequency with field intensities of 7, 12, and 15 kV/m respectively. To estimate the effect of the electric field on the organisms of the animals a group of the same methods was used as was used earlier by Ye. V. Prokhvatilo, I. P. Kozyarin et al. The investigations were conducted before the experiment was started (initial data) and 30, 60, 90 and 120 days after the start of irradiation of the animals.

Table 1. Indicators of the functional state of the organism of animals by the end of the experiment (M ± m)

1 Показатель	Напряженность поля, кВ/м 2			
	контроль 3	7	13	18
4 Проба с плаванием, мин	3.6 0.2	3.4 0.2	3.8 0.4	2.5** 0.2
5 Суммарная подпороговых импульсов, В	12.0 0.6	15.0** 0.7	18.9** 0.8	19.2** 0.8
6 Время латентного периода безусловного рефлекса, мс	47.6 1.3	74.8** 2.9	68.8** 1.7	78.8** 2.6
7 Активность холинэстеразы крови, мкг/мл в 1 мин	118.3 2.4	124.0 3.8	123.4 4.7	138.2** 4.7
8 Активность холинэстеразы ткани мозга, мкмоль ацетилхолина на 1 г ткани в 1 ч	1029.8 19.1	1023.1 21.9	993.7 33.9	791.7* 29.2
9 Содержание остаточного азота в крови, мг%	24.1 0.5	24.7 0.5	27.2** 0.6	31.6** 0.5
10 Содержание мочевины в крови, мг%	28.8 1.1	29.8 1.0	34.2** 1.3	43.1** 1.1
11 Содержание глюкозы в крови, мг%	72.0 2.1	74.6 1.7	85.6** 3.2	90.8* 4.5
12 Содержание гликогена в печени мг%	5269.2 263.4	3053.2** 146.1	3220.1** 128.8	3968.7* 183.4
13 Активность церулоплазмина крови, абс. ед.	37.6 1.9	36.8 2.1	41.2 0.8	46.0* 1.3
14 Насыщенность железом трансферрина крови, абс. ед.	0.26 0.01	0.24 0.01	0.20 0.01	0.16** 0.015
15 Степень дегрануляции базофилов, %	11.0 1.0	10.0 1.0	11.5 1.1	8.5 1.0
16 Процент бляшкообразующих клеток	3.14 0.2	2.60 0.2	2.72 0.2	2.61 0.2

17 Примечание. Здесь и в табл. 2 одной звездочкой отмечено $P<0,05$; двумя — $P<0,01$.

Key:

1 -- Indicator
2 -- Field intensity, kV/m
3 -- Control
4 -- Swimming test, minutes
5 -- Summary of subthreshold pulses, V
6 -- Time of latent period of unconditioned reflex, ms
7 -- Blood cholinesterase activity, micrograms/ml per minute
8 -- Brain tissue cholinesterase activity, micromoles of acetylcholine per g of tissue per hr
9 -- Residual nitrogen content in the blood, mg%
10 -- Urea content in the blood, mg%
11 -- Glucose content in the blood, mg%
12 -- Glycogen content in the liver, mg%
13 -- Blood ceruloplasmin activity, absolute units
14 -- Saturation of blood transferrin with iron, absolute units
15 -- Degree of degranulation of basophilic leukocytes, %
16 -- Percentage of plaque-forming cells
17 -- Note. Here and in Table 2, $P < 0.05$ is designated by * and $P < 0.01$ by **.

Presented in Table 1 are generalized results of investigations conducted at the end of the experiment. Those indicators are mainly presented on the basis of which a reliable difference was detected between the control and test groups of animals. In the course of the experiment no signs of deviation were registered in behavioral reactions and the body mass of animals of all test groups from the control. Ability to work (determined from the duration of swimming with a load of 10 percent of the body mass) of animals of groups 2 and 3 did not change in the process of the investigations, but in animals of group 4 (E = 15 kV/m) by the end of the experiment it had decreased and was 2.5±0.2 minutes as against 3.6±0.2 in the control ($P < 0.01$). In the study of the functional state of the nervous system very early shifts (in animals of groups 3 and 4 from the end of the first month of irradiation and in rats of group 2 from the second month) in comparison with the control were observed in the values of the summation-threshold indicators and the time of the unconditioned reflex latent period. Those indicators increased reliably (see Table 1), indicating disturbance of the interrelation of the principal nervous processes in the cerebral cortex with the prevailing of inhibition processes. Dynamic observation of the blood cholinesterase activity revealed a temporary increase of it in animals of groups 2 and 3 in the second and third months of irradiation, whereas in animals of group 4 (E = 15 kV/m) an increase of the blood cholinesterase activity was observed from the second month and before the end of the experiment. It is assumed that one of the reasons for increase of the activity of the enzyme under the effect of electromagnetic fields on the organism is increase of the permeability of the cell membranes. Evidently that is why a reduction of cholinesterase activity in brain tissues was observed in the test animals (see Table 1). In any case, the increase in the activity of the enzyme in the blood of animals of group 5 indicates disturbance of biochemical homeostasis which assures a stable course of nervous processes.

Changes of the functional state of the nervous system were reflected to a certain degree also in metabolic processes. Thus, in animals exposed to electric fields of industrial frequency with intensities of 12 and 15 kV/m during the entire course of the experiment a reliable rise of the residual nitrogen, urea and glucose in the blood was observed. The increase of the concentration of residual nitrogen and urea in the blood of animals exposed to the action of electromagnetic fields, in the opinion of S. V. Nikogosyan, is a result of intensification of dissimilatory processes in protein metabolism and disturbance of the dynamic equilibrium between proteins of the blood and tissues. At the end of the experiment a reliable reduction of the glycogen content in the liver was registered in animals of the test groups (see Table 1).

The immunological reactivity of the organism of experimental animals was judged by the degranulation of the basophilic leukocytes (Shelley's indirect test) and the Ierne-Klemparskaya reaction, which reflects the content of immunocompetent cells in the peripheral blood. In animals of the test groups in the course of the first 2 months of the experiment an intensification

of degranulation of the basophilic leukocytes in the Shelley reaction was observed after subcutaneous administration of tissue agent (brain tissue of an animal irradiated by an electric field of industrial frequency). Thus, in rats of group 2 ($E = 7$ kV/m) after 2 months of the experiment the degree of degranulation of the basophilic leukocytes was $14.0 \pm 1.0\%$ ($P < 0.05$), and in rats of group 4 ($E = 15$ kV/m) it was $27.0 \pm 1.6\%$ ($P < 0.01$). In the same animals intensification of the Ierne-Klemparskaya reaction was observed, which testifies to the development of an autoallergic process. These data are of special interest in connection with the fact that the possibility of autoallergy under the effect of ultrahigh-frequency energy had already been described earlier (O. I. Shutenko et al).

Also studied were the balance and interorgan exchange of a number of trace elements: copper, molybdenum, iron and manganese*. It is evident from the data of Table 2 that even brief daily irradiation of the animals with an electric field of industrial frequency causes reliable changes in the metabolism of trace elements, and in this attention is attracted by differently directed shifts in copper and iron metabolism. Thus, in animals of groups 3 and 4 ($E = 12$ and 15 kV/m respectively) a reliable increase was observed in the excretion of iron with the urine and feces and the content of that biotic was reduced correspondingly in the carcass. The iron content decreased both in its main place of deposit, the liver, and in a number of other organs (especially in rats of group 4), particularly in the blood (see Table 2). According to contemporary ideas (Bruschke) reduction of the iron level in the blood in combination with reduced saturation of the serum transferrin with iron, observed when there is a chronic deficiency of it in the organism and an increased expenditure of reserve iron (from storage), testifies regarding the stress and even the exhaustion of the adaptational and compensatory resources of the organism.

At the same time the excretion of copper from the organisms of test animals (especially of groups 3 and 4) declined and its content in the carcasses increased (see Table 2). Observed in that case was mobilization of copper from its main deposit, the liver, and its content in other organs and the blood increased. Since in irradiated animals the excretion with excrements of the physiological antagonist of copper, molybdenum, increased, the copper-molybdenum index increased in the tissues. It is assumed that the increase of that index intensified physiological processes in which copper participates and which are often observed during the stress of adaptive reactions of the organism. In connnection with elevation of the copper level in the blood, in the course of the experiment an increrse of the activity of the copper-containing protein of the blood serum ceruloplasmin, was observed in the irradiated animals (see Table 1).

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*The content of trace elements in tissues and the excretions of the animals were determined by quantitative spectrography with an ISP-28 quartz spectrograph (A. N. Zaydel'). The ceruloplasmin activity and saturation of the serum transferrin with iron were determined colorimetrically (G. A. Babenko).

Table 2. Content of copper, molybdenum and iron in tissues of experimental animals after 4 months of effect of electrical fields of industrial frequency (M ± m)

1 Объект исследования	2 Напряженность поля, кВ/м			
	3 контроль	3	12	18
	4 Медь, мкг%			
7 Печень	721,0±33,0	699,0±32,0	631,0±21,0	586,0±23,0*
8 Селезенка	45,0±1,8	57,0±3,4*	70,0±3,0**	129,0±6,4**
9 Головной мозг	164,0±11,0	169,0±10,0	171,0±7,0	202,0±8,0*
10 Миокард	119,0±5,0	141,0±7,0*	153,0±9,0**	182,0±9,0**
11 Кровь	60,0±3,6	60,0±3,0	73,0±3,0*	75,0±3,7*
12 Тушка, мкг	329,0±28,7	335,5±34,2	375,7±36,2	396,8±40,3
	5 Молибден, мкг%			
7 Печень	41,0±3,0	35,0±2,0	32,0±1,6*	29,0±1,2**
8 Селезенка	7,9±0,3	6,5±0,3*	3,8±0,2**	2,7±0,1**
9 Головной мозг	14,0±0,6	13,0±0,7	11,0±0,4**	9,7±0,5**
10 Миокард	3,3±0,1	3,2±0,2	2,9±0,1*	2,8±0,1**
11 Кровь	2,5±0,1	2,5±0,1	2,3±0,09	1,9±0,7**
12 Тушка, мкг	355,4±34,0	335,4±32,1	328,3±29,8	286,1±25,4
	6 Железо, мг%			
7 Печень	33,0±2,3	29,0±2,0	24,0±1,2**	18,0±0,7**
8 Селезенка	15,0±0,8	16,0±0,6	15,0±0,6	16,0±0,6
9 Головной мозг	14,0±0,8	13,0±0,7	12,0±0,7	11,0±0,6*
10 Миокард	2,8±0,1	2,8±0,1	2,8±0,1	2,9±0,1
11 Кровь	33,0±1,2	30,0±2,1	27,0±1,4**	24,0±1,2**
12 Тушка, мкг	22,6±1,8	18,4±1,7	16,6±1,1*	14,3±1,3**

Key:
1 -- Object of investigation
2 -- Field intensity, kV/m
3 -- Control
4 -- Copper, microgram-%
5 -- Molybdenum, microgram-%
6 -- Iron, microgram-%
7 -- Liver
8 -- Spleen
9 -- Brain
10 -- Myocardium
11 -- Blood
12 -- Carcass, micrograms

Thus it is evident from the presented materials that definite shifts on the part of the functional state of the nervous system and the trace element metabolism, even from a 30-minute daily action of an electric field of industrial frequency, start to be noted in animals of group 2 and attain very well-expressed changes in group 4. The described physiological and biochemical changes are reversible. One month after irradiation was halted all the studied indicators in animals irradiated earlier were the same as those of the control rats. The presented materials were used in normalizing the given factor of the external environment under the conditions of populated places, and also in the development of sanitary and hygienic measures directed toward preserving the health of the population.

Conclusions

1. Chronic action of electric fields of industrial frequency on the organism of animals causes changes of the functional state of the central nervous system, some metabolic processes, trace element metabolism and the protective forces of the organism, the manifestation of which depends on the field intensity.

2. It is recommended that a more thorough study be made of distinctive features of trace element metabolism in people exposed to the action of electric fields of industrial frequency under production conditions, that the physiological significance of observed shifts in the trace elements balance and interorgan distribution be clarified and that preventive measures be adopted (ultraviolet irradiation, prophylactic nutrition, etc).

BIBLIOGRAPHY

1. Babenko, G. A. "Mikroelementy v eksperimental'noy i klinicheskoy meditsine" (Trace Elements in Experimental and Clinical Medicine), Kiev, 1965.

2. Zaydel', A. N., et al. "Emissionnyy spektral'nyy analiz atomnykh materialov" (Emission Spectrum Analysis of Atomic Materials). Leningrad-Moscow, 1960, p 242.

3. Kozyarin, I. P., Gabovich, R. D., and Popovich, V. M. GIGIYENA I SANITARIA, 1977, No 4, pp 18-21.

4. Nikogosyan, S. V. Ibid., 1964, No 9, pp 56-57.

5. Prokhvatilo, Ye. V., et al. Ibid., 1976, No 8, pp 19-23.

6. Shutenko, O. I., et al. Ibid, 1977, No 8, pp 48-50.

7. Brushchke, G. In: Der Eisenstoffwechsel (The Metabolism of Iron). Dresden, 1964, p 243.

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LOW FREQUENCY DIELECTRIC DISPERSION OF BIOLOGICAL TISSUES

Kishinev ELEKTRONNAYA OBRABOTKA MATERIALOV in Russian No 3, 1979 pp 69-73

[Article by Yu. N. Levchuk and V. D. Dyshlovoy, Kiev]

[Text] Investigations of the mechanism of action of industrial frequency of electromagnetic fields (EMF i/f) upon biological objects include study of the dielectric parameters of living tissues in the low-frequency range. The difficulties of low-frequency measurements are generally known. Added to this actual complexity of structure of biological tissues is the added difficulty in interpretation of the results obtained. For example, presence of anomalous dispersion of dielectric losses in muscle tissues has been found in the region of 0.5-30 kHz /1-6/. However, these reports have not taken into account the pre-electrode processes going on during the measurements. Modeling of the phenomenon on a concrete electrical circuit has shown that the presence of an area of anomalous dielectric losses is not a specific property of living tissue and is determined simply by the schematic relationships of the parameters of an equivalent scheme of displacement of the pre-electrode processes /7/.

Rather frequently, dispersion of dielectric parameters of living body tissues is interpreted within the framework of the Debye theory, known to be accurate only for weak solutions of dipole molecules in non-polar solvents. In particular, Presman /8/ relies on the dielectric penetrability in muscle and fat tissues, starting from the Debye theory of polarization, considering, apparently, the coincidence of several calculated values of ε with the measured values to be fully adequate justification of the use of the Debye theory. Meanwhile, as has been shown by our calculation of the tangent of the angle of dielectric losses tg δ and the dielectric penetrability of muscle and fat tissues, the Debye theory, as applied to biological tissues, does not satisfy experimental data, in particular at low frequencies.

Table 1 presents the calculated dielectric parameters of muscle and fat tissues as a function of the logarithm of frequency lg ν. Calculations were made according to the Debye formula /9/, taking into account the presence of several values for the time of relaxation.

Table 1. Values of dielectric parameters of muscle and fat tissue calculated on the basis of the Debye mechanism of polarization

lg f	1.00	1.25	1.50	1.75	2.00	2.25	2.50	2.75	3.00	3.25	3.50	3.75	4.00
1. Мышечная ткань													
1	2,538	2,384	2,115	1,654	1,000	0,570	0,348	0,231	0,192	0,17	0,154	0,15	0,14
2	0,241	0,242	0,243	0,244	0,247	0,249	0,250	0,251	0,251				
3	170,9	102,8	65,40	47,22	44,46	44,19	41,13	34,78	23,54				
2. Жировая ткань													
1				0,188	0,125	0,092	0,072	0,060	0,046	0,038	0,03	0,02	0,02
2	0,023	0,024	0,024	0,025	0,026	0,026	0,027	0,028	0,029	0,029	0,03	0,031	0,03
3				42,57	37,44	28,61	21,35	14,94	11,35	7,73	5,69	3,4	2,8

3. Примечание. 1—относительная диэлектрическая проницаемость ($\varepsilon \cdot 10^{-6}$); 2—удельная проводимость (ρ, Ом$^{-1}\cdot$м$^{-1}$); 3—тангенс угла диэлектрических потерь tgδ.

Key
1. Muscle tissue
2. Fat tissue
3. Note. 1—relative dielectric penetrability ($\epsilon \cdot 10^{-6}$);
   2—specific conductance (ρ Om^{-1} · m^{-1});
   3—tangent of the angle of dielectric losses tgδ

Table 2. Experimental values of the dielectric parameters of various tissues of the human body

lg f	1	2	3	4	5	6	7	8	9	10
1. Кровь										
1				0,0028	0,0027	0,0020	$200\cdot10^{-6}$	$75\cdot10^{-6}$		
2		0,602	0,667	0,680	0,689	0,714	1,11	1,219		
3				42,95	45,26	6,3	9,99	2,92		
2. Легкие										
1	8,00	0,45	0,09	0,03						
2	0,091	0,090	0,100	0,105	0,505					
3	20,47	36,00	20,00	6,30						
3. Печень										
1	16,0	0,9	0,15	0,055	0,0095					
2	0,100	0,109	0,125	0,139	0,2177			$70\cdot10^{-6}$		
3	11,25	21,80	15,00	4,55	4,11					
4. Мышца										
1	10,0	0,80	0,13	0,05	0,02	0,002		$72\cdot10^{-6}$	$50\cdot10^{-6}$	$41\cdot10^{-6}$
2	0,104	0,112	0,125	0,132	0,192	0,400		0,667	1,333	8,333
3	18,72	25,20	17,30	5,75	1,73	3,6		1,67	0,48	0.37
5. Сердечная мышца										
1	6,0	0,80	0,3	0,1						$55\cdot10^{-6}$
2	0,104	0,109	0,125	0,167						1,111
3	26,74	24,53	7,5	3,01						0,364

6 Примечание. 1, 2, 3 то же, что и в табл. 1.

Key 1. Blood; 2. Lungs; 3. Liver; 4. Muscle; 5. Cardiac muscle; 6. Note. 1, 2 and 3 are the same as in Tab. 1

Table 3. Values of the coefficient of dielectric losses of various tissues of the human body

Органическая ткань	$\varepsilon\cdot tg\delta$			
	lg f			
	1	2	3	4
Мышца	1872	201,6	22,49	2,376
Сердечная мышца	1871,8	196,2	22,50	3,006
Легкие	1638	162	13,00	1,690
Печень	1800	195,7	22,70	2,502
Жировая ткань	230	24,7	6,19	1,955

Key. Left Column: Organic tissue--muscle, cardiac muscle, lungs, liver, fat tissue

Table 2 has generalized the experimental values of dispersion of dielectric parameters of various tissues of the human body, obtained from /10-24/. From comparison of Tabs. 1 and 2, it follows that the calculated values of tg δ, at frequencies lower than 100 Hz, are too high, as compared with the experimental values, by approximately an order. This overestimation cannot be explained by the higher values of the specific conductance assumed in the performance of the calculations. Evidently, it is wrong to extend the formal extrapolation of the Debye theory to such a complex system, which real biological tissues happen to be. Apparently, the Maxwell-Wagner polarization theory /25/, accurate for dispersion of spherical particles, also cannot account for all of the conjunction of dielectric phenomena going on in a bioorganic medium. Essentially new results are obtained in calculation, in the mechanism of Maxwell-Wagner polarization, of the influence of adsorbed layers and surface hydration upon dielectric properties. In particular, consideration not only of the electrical but, also, of the diffusion mechanism of transfer of current carriers, with polarization of a double electrical layer for particles of molecular sizes, is taken into account in the Debye-Falkenhagen theory /26/.

And, finally, studies of the influence of the diffusion mechanism upon polarization of disperse systems arrived at the conclusion, in reference to low frequency lag of the polarization field, that it leads to large values of low-frequency, dielectric penetrability /27/. Further development of the theory of dielectric phenomena of condensed disperse systems was noted within the framework of the multifield theory, taking into account mutual polarization of particles /28,29/. However, calculation of dielectric parameters, based on the multifield theory, leads to substantial mathematical difficulties and, in addition, this theory is not generalized to conducting systems.

Therefore, interpretation of data on low frequency dielectric dispersion of biological tissues involves a number of difficulties of a predominantly theoretical nature. Substantial simplification, in analysis of results of measurements, can be obtained in the presence of a methodology for measuring relaxation dielectric losses in tissues against a background of significantly superior losses of conductivity. Such a procedure has been worked out /30/ for liquids, and, at the present time, is being modified by us, primarily with biological specimens.

A very important feature of the action of low-frequency electromagnetic fields is the absence of proportionality between the absorbed energy and magnitude of the biological effect. For this reason, examination of only the energy aspect of interaction of an EMF with biological systems is not enough. From our point of view, this is explained in the following way. The usual tests to assay a response reaction of the body to the action of an EMF are performed, as a rule, at the body level (processes of reproduction, growth and development, survivability, sensitivity of the central nervous system, and so on). Meanwhile, disturbance, precisely of the interaction of various systems on the molecular, cellular and even on the bodily

level, under the influence of an EMF, is possible since the damaging effect of the low-frequency field, of itself, is not great. Here, probably, the clue to the non-proportional association of time of exposition and field voltage with magnitude of biological effect is also hidden. It is entirely possible that different physiological systems of the body have very great sensitivity to action of an EMF at a definite dose of it. And, it must be supposed, these doses are strictly differentiated at not only the molecular and cellular level but, also, at the bodily level. Here it is appropriate to give a simple example: it is difficult to read under poor illumination but it is even more difficult to read in the rays of a projector. That is, there is selective sensitivity of the visual organ to the magnitude of voltage of the field of a light wave. Hence, it can happen that different organs of an integral body, in a homogeneous EMF, will react to that field, to a different degree. Of course, there is the importance of the magnitude of the energy scattered in one or another type of tissue, or the so-called specific dielectric losses. The specific dielectric losses are calculated by the formula $p = E^2 \omega \epsilon \epsilon_0 \, tg\delta$, where E is the field voltage, ω the cyclic frequency and ϵ_0 the electrical constant.

For practical computation in the SI system it is possible to use the formula

$$p = E^2 \cdot \nu \frac{\epsilon tg\delta}{1.8 \cdot 10^{10}} \ (\text{Вт/м}^3); \quad \nu = \frac{\omega}{2\pi}$$

Here the product $E^2 \cdot \nu$ characterizes the external field and the dimensionless product $\epsilon \, tg\delta$ (coefficient of dielectric losses), the properties of the medium on which that field is acting. Tab. 3 presents our calculations of the values of the coefficient of dielectric losses for various types of biological tissues at frequencies of 10, 10^2, 10^3 and 10^4 Hz.

As follows from Tab. 3, only fat tissue varies strongly, with respect to absorption of the energy of an electromagnetic field, from the other types of tissues of the human body. And this is connected, first of all, with the substantially lower conductivity of fat tissue. As for the purely thermal effect of the action of the EMF, it is about the same for all the other types of tissues. At large values of EMF electrical voltage, a marked role is played by the rate of rise in the temperature in the field, $\frac{dT}{dt}$. This rate can be calculated, knowing the specific heat capacity and density σ of the tissues, with the equation $p = 4.18 \sigma \frac{dT}{dt}$ (W/m^3), where p is the specific dielectric losses.

As has already been said, examination of only the energy aspect of EMF action does not permit understanding of the primary mechanism of field action. According to Presman's concept /8/, the basic acting factor is

the external information introduced by the EMF into the biological medium. But the informational role of the EMF at the molecular level reduces to polarization of the bioorganic molecules and, possibly, to distortion of the molecular conformations. The energy of relaxation dielectric losses is spent upon this, while the heat losses are due, primarily, to the conductivity. For this reason, separate measurement of relaxation losses and losses of conductivity at low frequencies (including industrial frequencies) is a first-order task of experimental studies in this field.

Conclusions. 1. Within the framework of the Debye theory, calculations have been made of the low-frequency dielectric parameters of several biological tissues. Results of the calculations are compared with an experiment based on available literature data.

2. The inadequency of the Debye polarization theory and the Maxwell-Wagner polarization theory to explain the dialectric properties of living tissues has been shown.

3. It has been shown by calculation that the energy of a homogeneous electromagnetic field, when absorbed in various organs of the human body, is approximately equal.

4. Ways are noted for experimental study of low-frequency dielectric dispersion of biological objects, taking into account the features of the dispersion.

BIBLIOGRAPHY

1. Aladzhalova, N. A. and Maslov, N. M., DAN SSSR, Vol 15, No 2, 1957

2. Aladzhalova, N. A. and Mertsalova, S. N., BIOFIZIKA, Vol 3, No 1, 1958

3. Mertsalova, S. N., "Change in electrical parameters of smooth muscle in the mollusc during contractions of various type " (in Russian), Author abstract of a candidate's dissertation, Arkhangelsk, 1959

4. ——————————, TR. ARKHANGEL'SK MED. IN-TA, Vol 19, 1961

5. Barabashova, Z. I. and Moskalenko, Yu. E., BIOFIZIKA, Vol 6, No 3, 1961

6. Polivoda, A. I. and Mikhaylova, A. A., Ibid., Vol 5, No 5, 1960

7. Filanovskaya, T. P., Ibid., Vol 11, 1966, p 278

8. Presman, A. S., in the book "Electromagnetic field and living nature" (in Russian), Moscow, Nauka, 1968, p 35

9. Horn, G., Le caratteristiche passive dei sistem biologici. AUTOMAZ. E AUTOMAZ., Vol 9, No 5, 1965

10. Debye, P. and Ramm, W., ANN. PHYS., Vol 28, 1937

11. Cole, K. and Cole, R., Dispersion and absorption in dielectrics. I. Alternating current characteristic. J. CHEM. PHYS. Vol 9, No 34, 1941

12. Schwan, H. P., Electrical properties of living tissues. AMER. J. MED. SCI., Vol 215, No 233, 1948

13. Cook, H., The dielectric behaviour of some types of human tissues at microwave frequencies. BRIT. J. PHYS., 8, 285, 1951

14. ———————, Dielectric behaviour of human blood at microwave frequencies. NATURE, Vol 168, 1951, p. 247

15. ———————. A compration [sic] of the dielectric behaviour of pure water and human blood at microwave frequencies. BRIT. J. APPL. PHYS. 3, 249, 1952 /sic/

16. Schwan, H. P. and Li, K., Capacity and conductivity of body tissues at ultra-high frequencies. PROC. IRE, Vol 41, 1735, 1953

17. Schwan, H. P., Messung von elektrischen Materialkonstanten und Komplex-Widerstanden vor allen biologischen Substanzen. A. NATURFORSCH. Vol 8, No 3, 1953

18. ———————, Electrical properties measured with alternating current: body tissues--in: Handbook of Biological Data. National Research Council, Washington, 1956

19. ——————— and Kay, C., Specific resistance of body tissues. CIRCULATION RES., Vol 4, 664, 1956

20. ——————— and Carstensen, E., Dielectric properties of the membrane of excised erythrocytes. SCIENCE, Vol 125, 985, 1957

21. Handbook of Biological Data. National Res. Council, Washington, 1956

22. Roberts, J. and Cook, H. Microwaves in medical [sic] and research. BRIT. J. APPL. PHYS. 3, 33, 1952

23. Cook, H., A physical investigation of heat production in human tissues when exposed to microwaves. BRIT. J. APPL. PHYS. 3, 1, 1952

24. England, T. and Sharpless, N., Dielectric properties of the human body in the microwave region of the spectrum. NATURE, Vol 163, 1949, p 489

25. Wagner, K. W., ARCH. ELECTROTECH., Vol 2, 1914, p 271; Vol 3, 1914, 100

26. Fol'kengagen, F., ELEKTROLITY, Moscow, IL, 1934

27. Dukhin, S. S. and Shilov, V. N., In the book "Dielectric phenomena and the double layer in disperse systems and polyelectrolytes" (in Russian). Kiev, Naukova dumka, 1972, p 8

28. Brown, W. H., J. CHEM. PHYS., No 23, 1955, p 1514

29. Gunter, R. and Heiiech, D., Z. PHYSIK, No 185, 1965, pp 345-374

30. Birzhanov, K. Yu., "Dielectric relaxation in aqueous solutions and suspensions in aural and radiofrequencies" (in Russian). Author's abstract, candidate's dissertation. Leningrad, 1975

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INFLUENCE OF ELECTROSTATIC FIELDS ON RESPIRATORY ENZYMES

Yerevan BIOLOGICHESKIY ZHURNAL ARMENII in Russian No 2, 1979 pp 157-161

[Article by S. L. Mkrtchyan, Yerevan State Medical Institute "Biochemistry Dept, Biophysics Laboratory of TsNIL, " The Influence of Electrostatic Fields on the Activity of Certain Respiratory Enzymes"]

[Text] The activity of enzymes and intermediates of the respiratory chain of the hepatic metochondria of rats was investigated after exposure to an electrostatic field. A decrease in succinate dehydrogenase and succinate-cytochrome-s-reductase activity and activation of cytochrome oxidase following 24-hour and one-week exposure and of succinate dehydrogenase activity after one-hour of exposure were demonstrated. A comparative analysis of the results obtained and the data of polarographic investigation is performed. The role of hyperoxia arising in tissues as the result of the influence of the electrostatic field in the mechanism of the described changes is discussed, as well as the possibility of the direct action of the field on the molecules of the enzymes.

As is well known, the electrostatic field (ESF) exerts an influence on the tissue supply of oxygen and the energy balance of the organism (1,2). In an earlier report (3) we demonstrated rather significant shifts in oxygen absorption in the mitochondria of the livers of rats placed in EFS's. The objective of the present work was to study these changes in greater depth by determining the activity of succinate dehydrogenate (SDH), succinate-cytochrome-s-reductase and cytochrome oxidase following exposure to an ESF. On the basis of the activity of these mitochondrial enzymes it is possible to a certain degree to judge the aggregate work of the section of the respiratory chain transporting electrons from succinate to oxygen.

Materials and Methods

The experiments were conducted on white mongrel male rats weighing 150-180 g. An electrostatic field at an intensity of 2000 V/cm was created using a compensator type unit with strictly regulating electric parameters (4). The influence of three types of exposure to the ESF was investigated: one-hour, one-day and one-week (for 6 hr a day). The animals were sacrified immediately after exposure to the ESF, in 1, 4, 7, and 14 days. The mitochondria of the rat livers were extracted using Shneyder's well knwon method (5). Succinate dehydrogenase activity was determined spectrophotometrically by the change in the extinction of an artificial electron acceptor 2.6-dichlorphenolindolphenol at 600 nm. Phenazinemetasulfate was used as an intermediate electron carrier (6). Succinate-dicytochrome-s-reductase was measured using King's method (7) and using 2.6-dichlorphenolindolphenol as an artificial electron acceptor. Cytochrome oxidase activity was determined spectrophotometrically by the change in the hue of dimethylparaphenylenediamine during oxidation with cytochrome S at a wave length of 510 nm (8). We made a small modification in the method. SDH and succinate-cytochrome-s-reductase were expressed in nmoles of oxidized succinate per minute one 1 mg of protein (50-100 γ of protein per sample, determined by Lowry's method). Cytochrome oxidase activity activity was expressed in nmoles of oxidized dimethylparaphenylenediamine per minute on 1 mg of protein (20-30 γ per sample). Measurements were taken at 25 degrees on a Specord recording spectrophotometrometer (GDR).

Results and Discussion

Comparatively small changes in the activity of the enzymes under investigation were observed after one-hour exposure to the ESF (fig 1). Thus, SDH activity sharply increased immediately after exposure to the ESF, persisted at approximately the same level for 24 hours and for the remaining time of the experiment was at the level of the control. The activity of the other enzymes practically did not change, with the exception of succinate-cytochrome-s-reductase activity, which decreased 24 hours later.

Figure 2 presents concerning enzyme activity after 24-hour exposure to an ESF. It is interesting to note that the observed decrease in SDHase and succinate-cytochrome-s-reductase activity correlated well with the drop in the respiration rate, the increase in the time of phosphorylation noted by us in a previous report at the same exposure to the ESF (3). Here, however, we must note a difficult to explain rise in cytochrome oxidase activity within 24 hours while the activity of the other enzymes was barely distinguisable from the control.

The results obtained after one-week exposure to the field (fig 2) basically coincides with the data established after 24-hour exposure. Yet here as well a rather strong increase in cytochrome oxidase activity is observed--on the fourth day, however.

According to Pring and Chesu, the relation between the activated and non-activated forms of the respiratory chain is controlled by the concentrations of oxygen in the environment (9), and, as has been demonstrated, during

the initial phase of the action of the lowered concentrations of oxygen on the mitochondria activation of the respiratory chain occurs as a rule (10). On the other hand, it is known that hyperoxia exerts a toxic influence on the terminal oxyidation which is expressed in suppression of it (11).

In the model proposed by Kupriyanov et al, activation of the respiratory chain occurs when electron transport accelerates (12). Obviously the drop in the respiration rate caused by the increase in the concentration of oxygen following exposure to the ESF must be accompanied by inactivation of the intermediates of the terminal oxidation chain;this in fact was observed in our experiments (with the exclusion of the change in cytochrome oxidase activity).

An alternative hypothesis concerning the primary nature of the disturbance in the enzyme function during the suppression of tissue respiration has not been excluded. It is possible that these disturbances are the result of structural changes caused by the direct action of the ESF on the molecules of these enzymes. The basic feasibility of the appearance of conformational shifts in the macromolecules following exposure to the ESF was demonstrated in a number of works (13, 14). According to Gavrikovaya and Vinogradov's diagram (15) the electrostatic interaction between different charged groups of molecules plays an important role in the activation by the SDF. Moreover, here the localization of these groupings is most important,i.e.,the conformational changes may result in change in enzyme activity. The role of the structural shifts is also considerable in the functioning of other components of the respiratory chair. Thus, according to King's hypothesis (16) electron transfer is accompanied by conformational changes in the molecules of the carriers of the chain. An earlier hypothesized mechanism of the action of ESF's on biological subjects (14) suggests disturbance of the structural organization of the molecules, apparently as the result of the action of certain polarizing effects. And since the enzymes under investigation by us are large biomolecules the activation of which is accomplished basically through electrostatic interactions,the hypothesis of the direct influence on them of ESF's is apparently not without sense. Yet while the results of the experiments with SDH and succinate-cytochrome-s-reductase may be integrated in the light of these hypotheses, it is quite hard to do this with respect to cytochrome oxidase.

It was shown comparatively recently that after exposure of hemoglobin to an ESF disintegration of the protein part of its molecule occurs. The increase in the volume of all molecules resulting from this leads to the subunits of hemoglobin approaching stabilization of the hemoglobin bond, in turn causing strengthening of bond of oxygen with the hemoglobin molecule (13). Cytochrome oxidase, however, as is well known, is also a heme-containing protein (with, of course, a number of differences from the hemoglobin molecule). The mechanism of the interaction of cytochrome oxidase and O_2 is not identical with the mechanism of oxygen bonding with hemoglobin; however, according to Chans' data formation of a compound reminiscent of oxyhemoglobin is an intermediate stage in the process of terminal reduction of O_2. If that is the case, the ESF may somewhat retard the oxygen in such a compound (as in hemoglobin) and in this manner the speed of the entire oxidation chain must be limited. This is in fact noted in polarographic investigation.

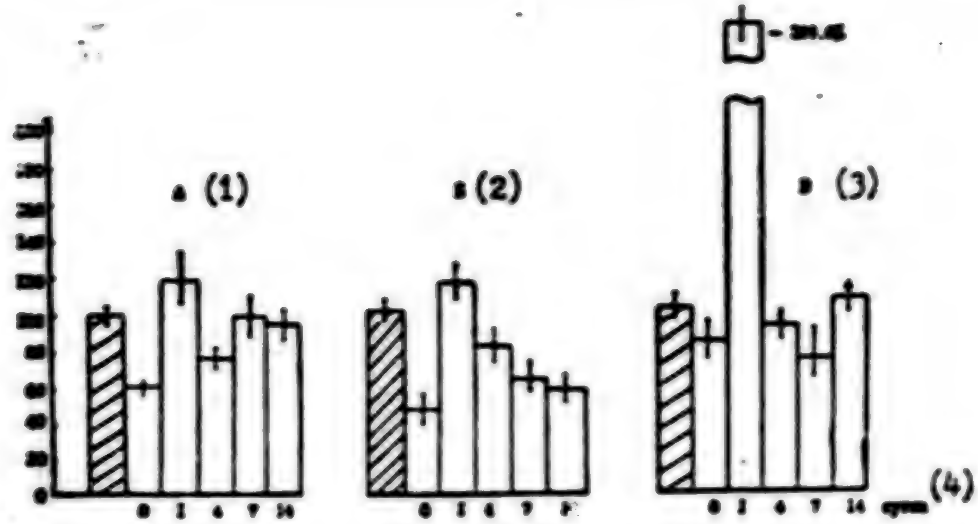

Figure 2. Twenty-four-hour exposure to an ESF. Designations are the same as in fig 1.

Key:
1. A
2. B
3. C
4. days

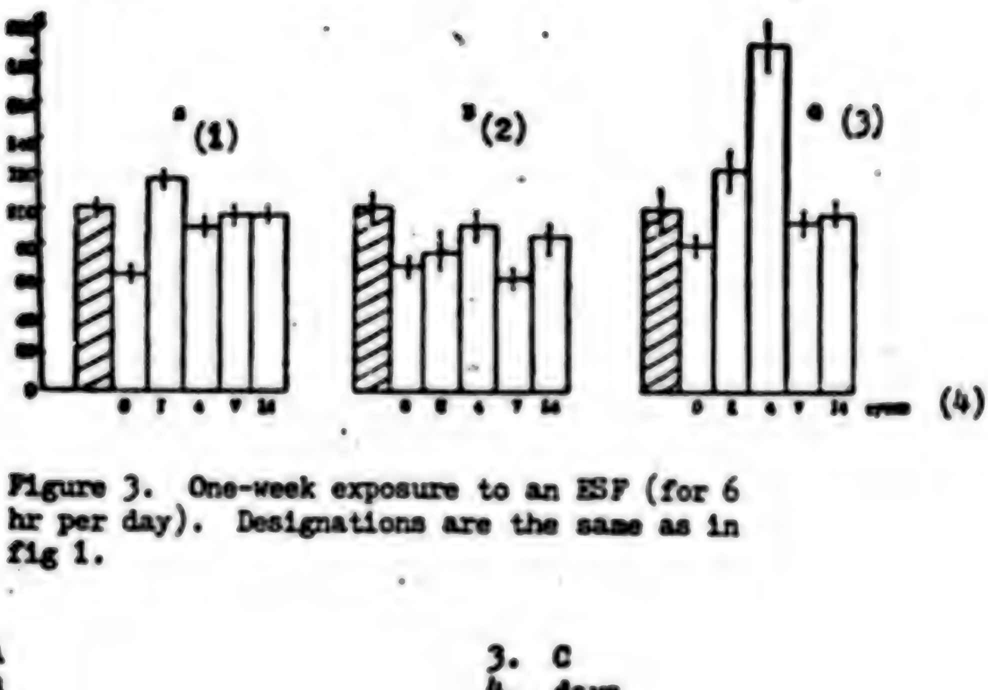

Figure 3. One-week exposure to an ESF (for 6 hr per day). Designations are the same as in fig 1.

Key:
1. A
2. B
3. C
4. days

cytochrome oxidase, however, is an enzyme with a rather high adaptive capacity, and maintenance of its activity within normal limits and sometimes even higher may apparently be explained as a certain compensatory effect.

In conclusion it must be noted that this account relates to the results of 24-hour and one-week exposure to the field. With one-hour exposure only SDH activity changed perceptibly. A comparison of these data with the insignificant values of the respiratory rate at the same exposure and tendencies to disturbance of respiration and phosphorylation suggests that activation by the SDH is a necessary link in the well known process of passing of the loosely conjugated mitochondria into a condition of free oxidation.

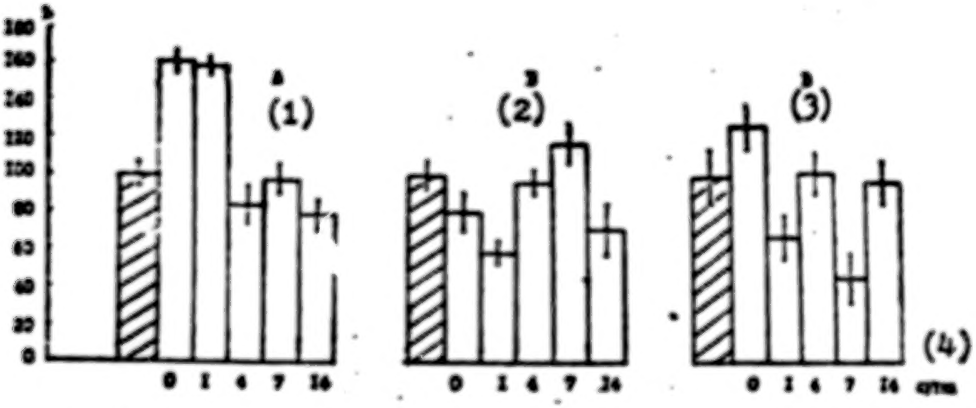

Figure 1. The activity of mitochondrial enzymes after exposure to an ESF for a one-hour interval. A=succinate dehydrogenase; B=succinate-cytochrome-s-reductase; C=cytochrome oxidase. The hatched column=the control

Key:

1. A
2. B
3. C
4. days

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EFFECTS OF SHF FIELDS ON MUSCLE OXYGEN TENSION AND TEMPERATURE IN RATS ADAPTED TO HYPOXIA

Kiev FIZIOLOGICHESKIY ZHURNAL in Russian No 4, 1979 pp 448-450

DEGTYAR', V. N., Kiev Institute of General and Communal Hygiene

[Abstract] Mongrel white rats, 130-150 g in weight, were used to test for the effects of superhigh frequency electromagnetic fields (50 $\mu W/cm^2$, 2375 MHz, 7h/day for 10 days) on oxygen tension and temperature of femoral muscles when acting alone or in conjunction with preadaptation to hypoxia (successive exposure in a pressure chamber to altitude equivalents of 2000 m, 3000 m, and 4000 m, 5 h/day for 7 days). In summary, the results showed that adaptation alone, the electromagnetic field alone, or the adaptation + electromagnetic field combination resulted in an immediate lowering of the temperature (34.08-35.22°C vs. control value of 37.30°C; $p < 0.001$); this difference persisted for a month (33.91-34.87°C vs. control value of 37.50°C). Muscle pO_2 was raised immediately from a control value of 21.96 mmHg by the electromagnetic field alone to 37.38 mmHg ($p < 0.001$), and to 29.88 mmHg by the adaptation + field combination ($p < 0.05$). Testing after a month revealed no significant differences in pO_2 between the experimental and control animals. These findings were interpreted to indicate that some of the redox processes were reversibly inhibited, and that lower elevation of pO_2 in preadapted animals reflected an increase in the number of electron transfer pathways and greater efficiency in the utilization of O_2. However, protracted depression of muscle temperature suggested that processes involved in heat formation remained depressed. Tables 1; references: 5 Russian.

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SENSITIVITY THRESHOLDS OF WHEAT STEMS AND ROOTS TO MAGNETIC FIELDS

Kiev DOPOVIDI AKADEMIYI NAUK UKRAYINS'KOYI RSR in Ukrainian No 7, 1979
pp 547-549

BOHATINA, N. I., VYERKIN, B. I., Academician, Academy of Sciences Ukrainian SSR, KULABUKHOV, V. M., LYTVYN, V. M., and NIKULINA, V. F., Physicochemical Institute of Low Temperatures, Academy of Sciences Ukrainian SSR

[Abstract] Investigations were conducted on the effects of various magnetic fields (2×10^{-4} to 10^4 Oe) on the rate of growth of roots and sprouts of Myronivs'ka 808 wheat plants. The results showed that the threshold of susceptibility was approximately 2×10^{-2} Oe. Certain seasonal parameters in the biologic effects of magnetic fields were apparent: during spring root elongation was increased by 25% while growth of stems was unaffected. At all other times of the year the effects on roots and stems were essentially identical. Figures 1; references: 1 Russian.

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